Clarence King

See Biographical Notice, p. 619.

TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF MINING ENGINEERS.

VOL. XXXIII.

CONTAINING THE PAPERS AND DISCUSSIONS OF 1902.

NEW YORK CITY:
PUBLISHED BY THE INSTITUTE,
AT THE OFFICE OF THE SECRETARY.
1903.

PREFACE.

In the final preparation of this volume for publication, I have to acknowledge the valuable aid of Dr. Joseph Struthers, for many years Editor of *The Mineral Industry*, and now Assistant Editor of the *Transactions* of the Institute.

R. W. Raymond.

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OFFICERS.*

For year ending February, 1903.

President.

EBEN E. OLCOTT, New York City.

Vice-Presidents.

CARLOS F. DE LANDERO......Pachuca, Mexico.
JOHN E. HARDMAN......Montreal, Canada.
JOHN HAYS HAMMOND......New York City.

(Term expires February, 1903.)

S. F. EMMONS......Washington, D. C.
JAMES GAYLEY......New York City.
J. HENRY LEE......Baltimore, Md.

(Term expires February, 1904.)

Managers.

D. H. BACON......Soudan, Minn.
E. V. D'INVILLIERS......Philadelphia, Pa.
WILLIAM KENT......Passaic, N. J.

(Term expires February, 1903.)

GEORGE A. CROCKER......New York City.
HORACE V. WINCHELL......Butte, Mont.
CLEMENS C. JONES......Richmond, Va.

(Term expires February, 1904.)

E. W. PARKER......Washington, D. C.
JAMES W. NEILL......Salt Lake City, Utah.
M. D. VALENTINE......Woodbridge, N. J.

(Term expires February, 1905.)

Secretary.

R. W. RAYMOND,
99 John St., New York City.

Treasurer.

THEODORE D. RAND,
Philadelphia, Pa.

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* The following officers were elected at the Annual Meeting, February, 1903. *President*, Albert R. Ledoux, N. Y. City; *Vice-Presidents* (to serve two years), John Markle, Jeddo, Pa.; Philip W. Moen, Worcester, Mass.; James F. Kemp, N. Y. City. *Managers* (to serve three years), Heinrich Ries, Ithaca, N. Y.; B. B. Lawrence, N. Y. City; F. Klepetko, Butte, Mont.; *Treasurer*, Theodore D. Rand, Philadelphia, Pa.; *Secretary*, R. W. Raymond, N. Y. City. (NOTE.—Mr. Rand resigned his position as Treasurer shortly before his death in April, 1903, and Mr. Frank Lyman, N. Y. City, was appointed his successor.)

HONORARY MEMBERS.

Prof. Richard Åkerman	Stockholm, Sweden.
Sir Lowthian Bell	Middlesborough, England.
Dr. Thomas M. Drown	South Bethlehem, Pa.
Prof. Haton de la Goupillière	Paris, France.
Prof. Hans Hœfer	Leoben, Austria.
Prof. Dr. Bruno Kerl	Berlin, Germany.
Prof. J. P. Lesley*	Philadelphia, Pa.
M. Floris Osmond	Paris, France.
Sir William C. Roberts-Austen†	London, England.
Prof. Dr. Hermann Wedding	Berlin, Germany.
Prof. Dimitry Constantin Tschernoff	St. Petersburg, Russia.

* Died June 1, 1903.

† Died November 28, 1902.

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* Annual meeting for the election of officers. The rules were amended at the Chattanooga meeting, May, 1878, changing the annual election from May to February.

† Begun in May at Easton, Pa., for the election of officers, and adjourned to Philadelphia.

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* Annual meeting for the election of officers.

† Begun in February at New York City, for the election of officers, and adjourned to Florida.

‡ " " " " " " " " " " " " " to Philadelphia.

PUBLICATIONS.

THE publications of the Institute comprise:

PAMPHLETS.

1. The minutes of the Proceedings of each Meeting.

2. Such of the papers presented or read by title at each Meeting as are furnished by the authors and approved by the Council for full publication. (In nearly all cases in which papers, the titles of which appear in the Proceedings, are not subsequently published, they have been withdrawn by the authors.) These papers are published separately in pamphlet form, and are marked "subject to revision." Beyond the edition distributed, without charge, to members and associates not in arrears, a small supply is retained to meet subsequent demand. There are no copies on hand of papers read before 1880. The stock is nearly complete from 1880. These papers are for sale at the office of the Secretary, or are sent to purchasers by mail or express, charges paid, on receipt of the price, as follows:

No. of Pages.	Single Copies.	10 Copies.	20 Copies.
8 or less.	$0 10	$0 60	$1 00
9 to 12 inclusive	0 10	0 80	1 40
13 to 16 "	0 12	1 00	1 75
17 to 20 "	0 16	1 25	2 25
21 to 24 "	0 20	1 50	2 75
25 to 40 "	0 25	2 00	3 50
41 to 56 "	0 30	2 50	4 50
57 to 72 "	0 35	3 00	5 00
73 to 88 "	0 40	3 25	5 25
89 to 104 "	0 45	3 50	6 00
105 to 120 "	0 50	3 75	6 25

Papers with folders and inserted plates subject to special price.

TRANSACTIONS.

The volumes of *Transactions*, which are published annually, contain the list of officers, rules, etc., the Proceedings, and the papers revised for final publication. (In this revision, after the preliminary publication, authors are permitted to use the largest liberty; and the changes and additions made in papers are sometimes important. It should be borne in mind by those who study or quote a paper in the preliminary edition, that they may not have in that form the ultimate and deliberate expression of the author's views. It should be added, however, that in the majority of cases there are no important changes.) These volumes are for sale as follows, in paper covers:

Vols. I. to IV., inclusive, each, ...	$3 00
Vols. V. to VIII., inclusive, each, ...	4 00
Vols. IX. and X. (a small supply only on hand), . . .	10 00
Vols. XI. to XXIX., inclusive, each, ...	5 00
Vols. XXX. and XXXI., each, ...	6 00
Vol. XXXII., ...	5 00

Half-morocco binding, $1 extra per volume.

INDEXES AND SPECIAL EDITIONS.

Index, Vols. XVI. to XX., inclusive, paper, ...	$1 00
Index, Vols. XXI. to XXV., inclusive, cloth, ...	1 25
Index, Vols. XXVI. to XXX., inclusive, cloth, ...	1 50
Indexes, Vols. I. to XV., XVI. to XX., XXI. to XXV., XXVI. to XXX., bound in one volume, cloth, .	4 00

"The Genesis of Ore-Deposits," comprising the famous treatise of the late Professer Franz Posepny, with the successive discussions thereof by Le Conte, Blake, Winchell, Church, Emmons, Becker, Cazin, Rickard and Raymond (all of which were published in Volumes XXIII. and XXIV. of the *Transactions* of the Institute, and subsequently in the special "Posepny Volume," issued by the Institute); also, later papers by Van Hise, Emmons, Weed, Lindgren, Vogt, Kemp, Blake, Rickard and others, and the discussions of these papers by De Launay, Beck, and many others (some of these were included in Volume XXX. and the balance will appear in Volume XXXI.); also a complete bibliography of the Institute papers and discussions on this subject from 1871 to the present time.

The original Posepny volume comprised 265 pages, and was sold for $2.50, at which price the edition was long since exhausted. The present volume is an octavo of 825 pages, bound in "book-linen," of the same color as the standard binding of the *Transactions*, ... $6 00

Half-morocco bound copies, ... 7 00

"The Evolution of Mine-Surveying Instruments." This is a volume of about 400 pages, issued in the same style as the foregoing, and containing the original paper of Mr. Dunbar D. Scott on that subject (*Transactions*, XXVIII.), first published in 1898, together with later papers, continuing the same subject, and discussions thereof, by Hoskold, Lyman, Davis and many others.

Memorial of Alexander L. Holley, with portrait, cloth, .	1 00
Glossary of Mining and Metallurgical Terms (1881), cloth, .	50
List of Members, Rules, etc., paper, ...	50

Authors' Editions of Pamphlets.

Extra copies, when ordered before the printing of the pamphlet edition, are furnished to authors, under Rule VII., at the following rates:

No. of Pages.	50 Copies.	100 Copies.	250 Copies.	Each additional 100 copies above 250.
4 or less	$1 25	$1 50	$2 25	$0 50
5 to 8 inclusive	1 75	2 25	3 25	0 75
9 to 12 "	2 25	3 00	4 25	1 00
13 to 16 "	2 75	3 75	5 25	1 25
17 to 20 "	3 25	4 50	6 25	1 50
21 to 24 "	3 75	5 25	7 25	1 75
25 to 28 "	4 25	6 00	8 25	2 00
29 to 32 "	4 75	6 75	9 25	2 25
Covers (including printing on first page of the same), extra	1 50	2 00	3 00	0 50

Papers with folders and inserted plates subject to special price.

All communications and remittances should be addressed to R. W. Raymond, Secretary, 99 John St., or P. O. Box 223, New York City.

RULES

ADOPTED MAY, 1873. AMENDED MAY, 1875, 1877, AND 1878, FEBRUARY, 1880, 1881, 1887, 1890, 1896 AND 1903.

I.

OBJECTS.

THE objects of the AMERICAN INSTITUTE OF MINING ENGINEERS are to promote the arts and sciences connected with the economical production of the useful minerals and metals, and the welfare of those employed in these industries, by means of meetings for social intercourse, and the reading and discussion of professional papers, and to circulate, by means of publications among its members and associates, the information thus obtained.

II.

MEMBERSHIP.

The Institute shall consist of Members, Honorary Members, and Associates. Members and Honorary Members shall be professional mining engineers, geologists, metallurgists, or chemists, or persons practically engaged in mining, metallurgy, or metallurgical engineering. Associates shall include all suitable persons desirous of being connected with the Institute, and duly elected as hereinafter provided. Each person desirous of becoming a member or associate shall be proposed by at least three members or associates, approved by the Council, and elected by ballot at a regular meeting (or by ballot at any time conducted through the mail, as the Council may prescribe) upon receiving three-fourths of the votes cast, and shall become a member or associate on the payment of his first dues. Each person proposed as an honorary member shall be recommended by at least ten members or associates, approved by the Council, and elected by ballot at a regular meeting (or by ballot at any time conducted through the mail, as the Council may prescribe) on receiving nine-tenths of the votes cast; *Provided*, that the number of honorary members shall not exceed twenty. The Council may at any time change the classification of a person elected as associate, so as to make him a member, or *vice versa*, subject to the approval of the Institute. All members and associates shall be equally entitled to the privileges of membership; *Provided*, that honorary members shall not be entitled to vote, and members or associates whose post-office address shall be outside of the United States, Canada and Mexico shall not be entitled to vote by mail, except upon proposed amendments to the Rules.

Any member or associate may be stricken from the list on recommendation of the Council, by the vote of three-fourths of the members and associates present at any annual meeting, due notice having been mailed in writing by the Secretary to the said member or associate.

III.

DUES.

The dues of members and associates shall be ten dollars, payable upon their election, and ten dollars per annum thereafter, payable in advance on the first day of each calendar year. Honorary members shall not be liable to dues. Any member or associate not in arrears may become, by the payment of one hundred and fifty dollars at one time, a life-member or associate, and shall not be liable thereafter to annual dues. Any member or associate in arrears may, at the discretion of the Council, be deprived of the receipt of publications, or stricken from the list of members when in arrears for one year; *Provided*, that he may be restored to membership by the Council on payment of all arrears, or by re-election after an interval of three years.

IV.

OFFICERS.

The affairs of the Institute shall be managed by a Council, consisting of a President, six Vice-Presidents, nine Managers, a Secretary and a Treasurer, who shall be elected from among the members and associates of the Institute at the annual meetings, to hold office as follows:

The President, the Secretary, and the Treasurer for one year (and no person shall be eligible for immediate re-election as President who shall have held that office subsequent to the adoption of these rules, for two consecutive years), the Vice-Presidents for two years, and the Managers for three years; and no Vice-President or Manager shall be eligible for immediate re-election to the same office at the expiration of the term for which he was elected. At each annual meeting a President, three Vice-Presidents, three Managers, a Secretary, and a Treasurer shall be elected, and the term of office shall continue until the adjournment of the meeting at which their successors are elected.

The duties of all officers shall be such as usually pertain to their offices, or may be delegated to them by the Council or the Institute; and the Council may in its discretion require bonds to be given by the Treasurer. At each annual meeting the Council shall make a report of proceedings to the Institute, together with a financial statement.

Vacancies in the Council may occur by death or resignation; or the Council may, by a vote of the majority of all its members, declare the place of any officer vacant, on his failure for one year, from inability or otherwise, to attend the Council meetings or perform the duties of his office. All vacancies shall be filled by the appointment of the Council, and any person so appointed shall hold office for the remainder of the term for which his predecessor was elected or appointed; *Provided*, that the said appointment shall not render him ineligible at the next annual meeting.

Five members of the Council shall constitute a quorum; but the Council may appoint an Executive Committee, or business may he transacted at a regularly called meeting of the Council, at which less than a quorum is present, subject to

the approval of a majority of the Council, subsequently given in writing to the Secretary, and recorded by him with the minutes.

V.

ELECTIONS.

The annual election shall be conducted as follows: Nominations may be sent in writing to the Secretary, accompanied with the names of the proposers, at any time not less than thirty days before the annual meeting; and the Secretary shall, not less than two weeks before the said meeting, mail to every member or associate (except honorary members) a list of all the nominations for each office so received, together with a copy of this rule, and the names of the persons ineligible for election to each office; and if the Council, or a Committee thereof, appointed for the purpose, shall have recommended any nominations, such recommendation may also be sent to members and associates with the said list of all nominations made, but not upon the same paper. And each member or associate, qualified to vote, may vote, either by striking from or adding to the names of the said list, leaving names not exceeding in number the officers to be elected, or by preparing a new list, signing said altered or prepared ballot with his name, and either mailing it to the Secretary or presenting it in person at the annual meeting; *Provided*, that no member or associate in arrears since the last annual meeting shall be allowed to vote until the said arrears shall have been paid. The ballots shall be received and examined by three Scrutineers, appointed at the annual meeting by the presiding officer; and the persons who shall have received the greatest number of votes for the several offices shall be declared elected, and the Scrutineers shall so report to the presiding officer. The ballots shall be destroyed, and a list of the elected officers, certified by the Scrutineers, shall be preserved by the Secretary.

VI.

MEETINGS.

The annual meeting of the Institute shall take place on the third Tuesday of February, at which a report of the proceedings of the Institute and an abstract of the accounts shall be furnished by the Council. Other meetings shall be held in each year, at such times and places as the Council shall select, and notice of all meetings shall be given by mail, or otherwise, to all members and associates, at least twenty days in advance.

Every question which shall come before any meeting of the Institute, shall be decided, unless otherwise provided by these Rules, by the votes of a majority of the members then present. Any member or associate may introduce a stranger to any meeting; but the latter shall not take part in the proceedings without the consent of the meeting.

VII.

PAPERS AND PUBLICATIONS.

The Council shall have power to decide on the propriety of communicating to the Institute any papers which may be received, and they shall be at liberty, when they think it desirable, to direct that any paper read before the Institute shall

be printed in the *Transactions*. Intimation, when practical, shall be given, at each general meeting, of the subject of the paper or papers to be read, and of the questions for discussion at the next meeting. The reading of papers shall not be delayed beyond such hour as the presiding officer shall think proper; and the election of members or other business may be adjourned by the presiding officer, to permit the reading and discussion of papers. The published papers and volumes of *Transactions* shall be distributed to all members and associates not in arrears, and may be sold to the public upon such conditions as the Council shall prescribe; but the Council may, in its discretion, omit sending to members and associates outside of the United States, Canada and Mexico, special circulars, unless the same contain proposed amendments to the Rules.

The copyright of all papers communicated to, and accepted by, the Institute, shall be vested in it, unless otherwise agreed between the Council and the author. The author of each paper read before the Institute shall be entitled to twelve copies, if printed, for his own use, and shall have the right to order any number of copies at the cost of paper and printing, provided said copies are not intended for sale. The Institute is not, as a body, responsible for the statements of fact or opinion advanced in papers or discussions at its meetings, and it is understood that papers and discussions should not include matters relating to politics or purely to trade; nor shall the Council or the Institute officially approve or disapprove any technical or scientific opinion or any proposed enterprise outside the management of the meetings, discussions and publications of the Institute, as provided in these Rules; *Provided*, however, that committees may be appointed by the Council or the Institute to make investigations and submit reports at meetings of the Institute; but no action shall be taken binding the Institute for or against the conclusions of any such reports.

VIII.

AMENDMENTS.

These Rules may be amended at any annual meeting by a two-thirds vote of the members present; *Provided*, that written notice of the proposed amendment shall have been given at a previous meeting; *and Provided, also*, that the amendment or amendments so adopted shall be printed upon a ballot and sent, not later than the next distribution of printed matter, to all members and associates not in arrears for the preceding year (except honorary members and foreign members elected before February, 1880), and each person receiving the same shall be requested to return it to the Secretary with his written vote of Yes or No to each amendment, and his signature; and the President shall appoint as Scrutineers three members or associates, who shall examine all of the said ballots which shall have been returned within one month from the date of their distribution, and shall report the result; and the Secretary shall publish and distribute to members, not later than the next distribution of printed matter, an announcement of the said result so reported, together with the text of the additional or amended rule or rules so adopted; and the amendment or amendments approved by the majority of the ballots so returned and reported shall become part of these Rules from and after the publication of said announcement by the Secretary.

Proceedings of the Eighty-Second (Thirty-Second Annual) Meeting, Part I.
New York City, February, 1902.

THIS meeting, so far as the above time and place are concerned, consisted of a single, purely formal session, held, as prescribed by Rule VI., on February 18, 1902, at the office of the Secretary, 99 John Street, New York City, for the counting of ballots, the presentation of the Annual Report of the Council, etc.

The reasons for this arrangement were stated in the Secretary's Circular, No. 6, of 1901, as follows:*

"The recent Mexican Meeting of the Institute was one of great international, as well as technical, significance, and its complete and brilliant success, due chiefly to the liberal encouragement of the Federal and State governments of Mexico and the enthusiastic generosity of other citizens throughout the Republic, as well as to the large attendance from the United States, has involved an unusual amount of time and labor on the part of the officers of the Institute, and still entails an extraordinary amount of publication and correspondence upon this office. It is consequently impracticable to organize another meeting for February next.

"The Council has, therefore, directed that the meeting of the Institute shall consist of a single, purely formal session, to be held, as prescribed by Rule VI., on February 18, 1902, at noon, in the office of the Secretary, 99 John Street, New York City, for the purpose of the counting of ballots and the presentation of the Annual Report of the Council, which will be subsequently printed and distributed, as usual. The titles of all papers accepted will also be presented, and these papers will be printed and distributed for discussion at a later meeting, or adjourned meeting bearing the same number, as may be hereafter decided, which will take place in the spring, at a time and place to be hereafter announced."

The session began at the time and place above-named.

Messrs. Anton Metz, B. Dunham and P. F. O'Rourke were appointed Scrutineers.

The Annual Report of the Council was presented, as follows:

ANNUAL REPORT OF THE COUNCIL.

In accordance with the Rules, the Council makes the following report to the Institute:

The financial statement of the Secretary and the Treasurer shows receipts from all sources for the year ending December 31, 1901 (including the balance of $1478.12 on hand December

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* This announcement was substantially repeated in Circular No. 1 of 1902.

31, 1900), of $39,059.55, and expenditures of $34,321.25, leaving $4748.30 cash on hand. No account is taken in this statement of the increased value of the assets of the Institute in back-volumes of the *Transactions*, office-furniture, etc. In addition to the cash on hand, the Institute possesses invested funds of the par value of $15,900 and market value of more than $20,000, yielding about $950 interest annually; and on December 31st there were no bills payable, or outstanding obligations.

The detailed statement is as follows:

Receipts.

Balance from statement of December 31, 1900,		$1,478 12
Annual dues,	$26,648 32	
Life membership,	3,761 17	
Binding of *Transactions*,	2,492 63	
Sale of publications,	3,664 50	
Electrotypes,	48 02	
Interest on bonds and deposits,	975 39	
Miscellaneous,	1 40	
		37,591 43
		$39,069 55

Disbursements.

Printing volume xxx. of *Transactions* of 1900,	$3,561 72	
" pamphlet edition of papers,	3,824 53	
" new volume on Ore-Deposits,	1,105 80	
" circulars and ballots,	280 27	
Binding volume xxx. and miscellaneous volumes of *Transactions*,	2,642 83	
" exchanges,	208 20	
Engraving and electrotyping,	1,002 14	
Secretary's department, including clerks, stenographers, and expenses of editing and proof-reading,	8,980 00	
Postage, including post-office box rent,	2,332 37	
Stationery,	757 70	
Rent,	2,500 00	
Express and freight charges,	1,420 83	
Telephone,	137 22	
Telegrams, cablegrams and car fare,	68 34	
Office equipment,	131 06	
Assistant Treasurer's department,	3,672 03	
Storage of *Transactions*,	112 84	
Special stenographers and expenses of meetings,	583 70	
Office supplies and repairs,	464 82	
Insurance,	26 98	
Collection charges,	7 52	
Extra clerical help,	106 32	
Library addition and catalogist,	393 03	
		34,320 25
		$4,749 30

Volume XXX. of the *Transactions*, an octavo of 1157 pages, issued and distributed during the year, is one of the largest ever printed by the Institute, and is unquestionably equal to any of its predecessors in the value of its contents.

It is but fair to mention, as contributing to the labors and expenses of the year, the preparation of two special additional volumes of considerable size, both of which will be issued in 1902, viz.:

1. The special volume on the genesis of ore-deposits, a republication of the former "Posepny" volume (containing the memorable treatise contributed to the *Transactions* in 1893 by the late Franz Posepny, and the discussion thereof by numerous contributors), together with important papers and discussions of later date by many eminent European and American authorities, and constituting a summary of the present state of the science of ore-deposits. Although the several contributions included in this volume are accessible to members in the volumes of our *Transactions* for the last 8 years, it is believed that this collection of them in one book, duly indexed, will be welcomed by instructors, students, and active mining engineers.

2. The special volume on mine-surveying instruments, containing the original paper of Mr. Dunbar D. Scott on this subject, with much valuable criticism and additional information, contributed by experts in other countries as well as in the United States.

Moreover, it should be added that a consolidated index to Volumes XXVI.–XXX., inclusive, was prepared during the year, and will be issued to members early in 1902. It is, perhaps, unnecessary to say that the preparation of such analytical indexes, at intervals of five years, has been believed, and has proved itself, to be a most important means of making our *Transactions* a convenient cyclopædia of practice and progress for all students of modern mining and metallurgy.

Two meetings have been held during the year: the LXXXth (XXXIst Annual) meeting, in February, and the LXXXIst, in the City and Republic of Mexico, in November. The published *Proceedings* of these meetings, with the appended description of the entertainments and excursions connected therewith, obviate the necessity of any further comment in this report. Vols. XXXI. and XXXII. of the *Transactions* will sufficiently prove

the amount, variety and value of the technical contributions elicited; and it is sufficient to say, here, that the year 1901 has rather raised than lowered the standard of pleasure and profit set up in previous years for the meetings of the Institute.

The exceptional labor and responsibility devolved upon the Secretary of the Institute in connection with the meetings and the publications of the year was doubled by the death of his son, who had been for many months his chief editorial assistant. At a meeting of the Council, held Dec. 17, the following minute was adopted:

"The Council desires to place on record its deep sense of the loss sustained, not only by the Secretary himself, but also by the American Institute of Mining Engineers, through the death, October 28, 1901, of Mr. Alfred Raymond, the only son and for many months past the efficient editorial assistant, of Dr. R. W. Raymond, Secretary of the Institute.

"At successive meetings of the Institute, and in correspondence or personal intercourse with its members, Mr. Raymond had won a wide and hearty recognition of his brilliant talents and charming personal character. His removal by death in the prime of his useful and most promising career deprives his parents of the dearest of sons, his innumerable friends of a cherished companion, the Institute of an esteemed and beloved servant, and the world of a devoted, generous and active lover of mankind."

Changes in membership have taken place during the year as follows: 301 members and 25 associates have been elected; 6 associates have become members; the deaths of 24 members and 7 associates have been reported; 40 members and 1 associate have resigned, and 24 members and 3 associates have been dropped from the roll by reason of non-payment of dues, loss of correct address, etc.*

	H. M.	F. M.	M.	A.	Totals.
At date of last report	11	31	2586	171	2799
Gains: By Election			301	25	326
" " Change of Status			6		6
Losses: By Resignation			40	1	41
" " Dropping			24	3	27
" " Change of Status				6	6
" " Death	1		24	7	32
Total gains			307	25	332
Total losses			86	18	106
Present membership	10	31	2788	174	3025

* Many of these, no doubt, will be reinstated, as has been the case in former years.

The list of deaths reported during the year comprises the following names:* *Honorary Member.* Joseph Le Conte (1895). *Members and Associates.*—Carl Angström (1885), C. S. Batterman (1901), R. C. Chambers (1886), S. S. Chisholm (1897), Frank E. Corbett (1899), Albert Couro (1888), E. C. Darley (1883), W. H. Emanuel (1881), Mario Escoban (1893), Albert H. Halder (1891), Mellen S. Harlow (1895), W. E. Johnson (1898), Clarence King (1899), Porter King (1897), W. J. Koehler (1891), G. A. Kornberg (1895), James F. Lewis (1875), E. N. Lindsay (1900), Duncan M. Maclaren (1898), Charles A. Macy 2d (1894), Thomas S. McNair (1877), James E. Mills (1877), James Moore (1875), S. Fisher Morris (1874), Frank Owen (1894), R. P. Rothwell (1871), William Van Slooten (1884), Joseph R. Walker (1885), Edward Walsh, Jr. (1874), William Watson (1897), Frank Williams (1888).

Biographical Notices of Joseph Le Conte, Clarence King, James F. Lewis and R. P. Rothwell have been prepared separately, and will be published in the *Transactions*. Concerning the remainder of the above list, such data as the Secretary has been able to obtain are given below, in the alphabetical order of the names. Any appropriate biographical data concerning these names, or others of the above list, which may be received hereafter, will be included in the next annual report.

Christopher S. Batterman was born in 1859 at Placerville, Cal., and educated at the University of California, from which he was graduated in 1879 as mining engineer—a profession towards which he naturally inclined, his father having been a mine-superintendent on the Comstock lode, Nevada, in the days of its greatest glory. He was subsequently employed as a mine-surveyor or manager in Mexico, Arizona, Nevada, Colorado and Montana. As the designer of an improved mining-transit, he is mentioned in our *Transactions*.† Mr. Batterman frequently appeared in mining lawsuits as an expert witness. He became a member of the Institute only a few months before his death, which occurred Oct. 7, 1901, at Butte, Montana. At the time of his death he was Chief Engineer of the Amalgamated Copper Company and Superintendent of the

* The figures in parenthesis indicate the year in which the persons named were elected by the Institute.

† *Trans.*, xxviii., 728.

mines of the Boston and Montana Cons. Copper and Silver Mining Co. of Butte.

R. C. Chambers became a member of the Institute in 1886. He died in April, 1901, at Salt Lake City, where he had been for many years prominent as a mine-manager, mine-owner, and expert adviser of wealthy capitalists engaged in mining ventures. The celebrated Ontario mine, in Utah, is but one of the properties selected by his judgment, and developed by him or under his advice, which have proved for long periods profitably productive. Indeed, for many years the "Chambers Syndicate," represented by him, was regarded throughout the Rocky Mountain region as a combination of capital sagaciously directed in its investments, bold in its enterprises, and not easily discouraged, or thwarted by lack of means, in their execution.

Frank E. Corbett, born in 1864, died at Butte, Montana, March 14, 1901. He was a native of Virginia, and a graduate of the law department of the famous University of that State, planned and established by Thomas Jefferson. In 1889, at the early age of 25, he took up his residence in Butte City, where he engaged in the practice of law. His refined nature, winning personality, intellectual power, professional skill and wide culture, both securing and holding for him an important clientage, soon made him eminent and successful. On one side or the other, he appeared as counsel in nearly all the important mining lawsuits tried in Butte after his arrival there; and it may be added that this statement covers a period during which that place was the scene of contests probably exceeding, in the aggregate value of the interests at stake, the contemporaneous similar litigation in all other parts of the United States.

Like other leaders of the Western bar called to deal with the intricate problems raised by the obscure, inadequate and inconsistent features of the U. S. mining law, Mr. Corbett appreciated fully the value of the contributions made in the *Transactions* of this Institute to the science of ore-deposits; and in 1899 be became an Associate of the Institute, in order to avail himself of the new light thus afforded to the legal as well as to the technical student of such subjects.

Not only at the bar, but also in politics, he achieved an early distinction, without sacrifice of honor or reputation. He was

Speaker of the Seventh Legislative Assembly of Montana, which adjourned but six days before his death; and when he passed away, in the full vigor of his prime, after a short attack of pneumonia (that awfully frequent and swiftly fatal scourge of high altitudes), friends and foes alike joined to praise and to mourn him.

Edward C. Darley was born in 1846 in New York City; became a mechanical and constructing engineer, and was for many years connected with James T. Witherow and Co., of Pittsburg, Pa. In this capacity he superintended the construction of the blast-furnaces of the Watts Iron and Steel Co., Middlesboro', Ky.; the Oswego Iron and Steel Co., Oswego, Oregon; the Ashland Iron Co., Ashland, Wisconsin; and the Vulcan Iron Works, St. Louis, Mo. He died at Chicago in April, 1901.

William H. Emanuel was born in 1860 in Catasauqua, Pa., where he died May 8, 1901. After a preliminary public-school education he entered Lafayette College, Easton, Pa., where he was graduated in 1881. Subsequently he was for two or three years chemist of the Repauno Chemical Company, manufacturers of high explosives, at Repauno, N. J., not far from Chester, Pa., and the Du Pont Powder Company of Wilmington, Del., both of which were under the direction of Mr. E. J. Du Pont (afterwards killed by an explosion at the latter works). In 1885, by reason of his health, he went to Colorado, where, in 1886, he succeeded his father as the agent for that region of the Laflin & Rand Powder Company, to which business was soon added the agency for the Rand Drill Company. His energy and success in these positions led to his appointment (with the consent, and, indeed, at the suggestion, of Mr. A. C. Rand), as agent for Frazer & Chalmers, the well-known makers of mining, milling and metallurgical machinery. It is strong proof of his ability and loyalty, and of the confidence reposed in him, that he acted for years as agent, at one and the same time, for all three of the concerns mentioned, neither of which had reason to feel that it would be better served by a representative giving his whole time to its interests alone. His labors in this triple capacity involved much travel and a wide acquaintanceship; so that he was personally known and highly esteemed in New York and London, as well as in Denver and

San Francisco, and throughout the Pacific coast States and Territories.

Albert Herbert Halder, who died in London, June, 1901, was a fellow of the Royal Institution of British Architects and a member of the Federated Institute of Mining Engineers, the Austrian Institution of Civil Engineers and Architects, and the American Institute of Mining Engineers. He joined the Institute in 1891, and after that date was engaged as a mining engineer in Rhodesia and the Transvaal, in South Africa, and in British Columbia. He returned to South Africa at the end of 1900, but apparently was not then able to resume work in the mining district; at least, his final residence, whether resumed by reason of illness or for some other cause, was London.

William Ellery Johnson was born in 1856 at Hopkinton, Mass. His parents moved in 1857 to Iowa Falls, Iowa, where he received a public-school education, which he supplemented with a college course at the State University, Iowa City. In 1878 Mr. Johnson went to Southern Colorado, where he was engaged in railway-surveys in the neighborhood of Alamosa. In 1879 he settled at Cañon City, where he started the Cañon City Water Co., and pushed its works to completion. In 1880 he took charge of the operations of the Colorado Fuel and Iron Co. in Gunnison and Garfield counties, and of the building of the Aspen and Western railroad to the coal-mines of that company. In 1885 he and his associates established at Florence, Colo., the Florence Oil and Refining Co., one of the earliest representatives in the State of that productive and useful industry. About 1892, induced by the dawning importance of the Cripple Creek district, he conceived the plan of the Florence and Cripple Creek railway—a line, forty miles long, which involved great engineering difficulties, but, once constructed, became, and has remained ever since, one of the most profitable, in proportion to its length, in the world. In these and other like enterprises in railway-building, mining, smelting, etc., he accumulated an ample fortune for himself, and, at the same time contributed greatly to the development of the mineral resources of his adopted State, in which he cherished an enthusiastic faith.

Walter J. Koehler died from heart-failure on the 24th of

April, 1901, at the Bellevue mine, Mount Sir Samuel, West Australia. He was graduated from the Massachusetts Institute of Technology, Boston, Mass., in 1881, with the degree of S.B., and for two years thereafter was chemist of the Pueblo Smelting and Refining Co., Pueblo, Colo. In 1883 he became assistant metallurgist of the same company. From 1885 to 1888 Mr. Koehler was employed by the Graphite Mining and Smelting Company of Socorro, N. M., and at Parral, Chihuahua, Mex. In 1888 he went to Broken Hill, New South Wales, as assistant superintendent of the smelting-works of the Broken Hill Proprietary Co., and became successively assistant, and afterwards chief metallurgist, of that company. During 1899, 1900 and 1901 he was general manager of the Western Australian Smelting Co. at Freemantle, and afterwards at Beaconsfield. At the time of his death he was interested in the treatment of the complex gold-ores of the Bellevue mine at Mt. Sir Samuel, West Australia.

Charles A. Macy, 2d, born at New York City in 1874, became an associate of the Institute in 1894, while still an undergraduate student at the Columbia School of Mines in New York. By reason of impaired health, he did not graduate in 1895 with his class, but subsequently received in 1899 his degree as mining engineer, and in that year became a member of the Institute. Unfortunately, he never recovered his strength, and, after years vainly spent for this purpose in travel and rest, he died August 28, 1901, without having fulfilled by actual achievements the promise of his youth.

Thomas S. McNair, born 1824, in Hanover, Pa., studied at Williams College, Mass., and subsequently taught school for a number of years, but ultimately adopted the profession of engineering. He was connected with the construction of the Raritan and Passaic Canal from Easton to Perth Amboy; was assistant division-engineer under W. F. Shunk (one of the most famous men of his time in that line) in the building of the North Penn railroad between Bethlehem and Philadelphia; and was also employed as an engineer in the construction of the Lehigh canal.

About 1854, while still a young man, he made Beaver Meadow, Pa., his residence. Somewhat later, together with

the late W. R. Maffet, he built that part of the North Branch canal which, extending from Wilkes-Barre to the New York boundary, was subsequently transferred to the Lehigh Valley Railroad Co., and abandoned. Many such early internal waterways have long since become of subordinate importance, or have disappeared altogether, in competition with later means of transportation. But in their time they aided mightily in the commercial development of the country; and their constructors were the leaders of American engineering.

A little later, Mr. McNair moved to Hazleton, Pa., where he resided until his death on July 25, 1901. The occasion of this change was his acceptance of the position of chief engineer of the Hazleton, subsequently merged into the Lehigh Valley, railroad. Under both administrations, he retained his position until 1893. Under his direction the tunnel between Hazleton and Jeddo and the link between Hazleton and Pottsville were constructed. The Harleigh canal and the famous Jeddo tunnel are witnesses of his skill as an engineer. He became, in 1871, and remained until his death, a member of the Institute.

James E. Mills was born in Bangor, Me., February 13, 1834, and died July 25, 1901, at San Fernando, Durango, Mexico. At the age of eighteen he went to Cambridge, Mass., and spent six years in the Lawrence Scientific School of Harvard University, where, after taking his degree as Bachelor of Science, he became an assistant in the laboratory of Prof. Agassiz. Here he met Joseph Le Conte, who just preceded him in graduation from the scientific school. Subsequently, at the suggestion of Agassiz, he made a careful geological survey of the Sierra Nevada in Plumas county, Cal.; and the results of his labor exist in accurate detailed maps, showing the formation of the Sierra, the changes of its water-courses, and the causes therefor. He was connected until his death with various mining interests; and his last work was the development of the great gold-mine at San Fernando, in Durango, Mex., and the design and construction of one of the most perfect milling-plants of its size in the world. At the time of his death he was, as he had been since 1895, consulting geologist of the Anglo-Mexican Mining Co.

Samuel Fisher Morris, born at Pottsville, Pa., in 1848, was a lineal descendant of Robert Morris, the eminent financier of

the American Revolutionary period, and belonged to a family closely connected, during following periods, with the mining and iron industries. It was therefore natural that he should adopt engineering as a profession, and associate himself with various enterprises directed to the development of the mineral resources of the United States. He was at one time superintendent of the mines and furnaces at Quinnimont, W. Va., and, somewhat later, an assistant of Mr. J. H. Bramwell in the important and fruitful pioneer work with which Mr. Bramwell's name is associated. For some years he was an engineer of the New Croton Aqueduct Commission of New York.

Mr. Morris was honored at different times by different governors of West Virginia with appointment as a member of public commissions requiring professional knowledge and practical judgment. He was an intelligent and fluent writer, and contributed, in 1880, to the *Transactions* of the Institute an able paper on the "New River Coal Field of West Virginia." At the time of his death, from heart-failure, which occurred June 13, 1901, at Eckman, W. Va., he was superintendent of the mines of the Pulaski Iron Co. of that place. Mr. Morris was universally esteemed as an engineer of accomplished skill, wide experience and absolute integrity.

Frank Owen was born at London, Eng., in 1869. He received his early education at the Whitgift School, Croyden, Surrey, and later he attended the Royal School of Mines, London, graduating therefrom in 1889. His first professional work was at the Frontino and Bolivia mines, near Remedios, Antioqua, Colombia; he then went to the El Callao mines, Venezuela, and remained there several years. He then returned to England, and subsequently was engaged in the examination of mining properties in South Africa, West Australia, Siam, Straits Settlements, Norway, Spain and the United States. In November, 1900, Mr. Owen took charge of an expedition to explore for gold in West Africa, and shortly after his arrival at Gold Coast he contracted a fatal illness, and died on July 13, 1901. His contributions to the *Transactions*, though only in the way of discussion of the papers of other authors, were both versatile and valuable, as the following list of subjects will indicate: Accumulation of Amalgam on Copper Plates (xxvi., 1049); Mining in Colombia (xxviii., 804); Mines of the Fron-

tino & Bolivia Co. (xxviii., 908); Equipment of Camps and Expeditions (xxix., 1030); Evolution of Mine-Surveying Instruments (xxx., 795). He wrote also for the IXth volume of *The Mineral Industry* a very thorough and able review of the Tin Industry of the Malay Peninsula, to the end of 1899.

Edward Walsh, Jr., born in 1849, died in 1901, *en route* from his home in St. Louis, Mo., to the Hot Springs of Virginia. At the time of his death he was one of the leading citizens of St. Louis, President of the Mississippi Glass Works, and connected as officer or director with numerous social or commercial organizations. At one time he had served his city as Water Commissioner.

Mr. Walsh became a member of the Institute in 1874, at which time he was specially interested in the manufacture of charcoal-iron. At the St. Louis meeting, October, 1886, he presented an elaborate and important paper* on "The Irregularities of the Blast-Furnace Process, and the Best Way to Avoid Them," to which he added, at the New York meeting, February, 1889, a "Supplementary Note on Blast-Furnace Lines." These papers must be ranked among the most creditable of the contributions to the metallurgy of iron (or, more precisely, to the theory and practice of the iron blast-furnace) elicited from American sources by the scientific treatises of Lowthian Bell and other authorities. They evince a familiarity with the literature of the subject, as well as the details of actual practice; and, although the later blast-furnace practice, with its immensely increased dimensions of stack, pressure and temperature of blast, speed of smelting, and consequent amount of daily product, has radically changed both the problems and the factors with which Bell and his pupils and critics had to deal, these papers, like others of their kind to be found in our *Transactions* for that period, are still worthy to be studied as specimens of the scientific method, candid temper, patient industry and spirit of hearty co-operation with which, in every epoch of technical progress, the pregnant questions of that epoch can be most fruitfully handled. In the manufacture of glass, to which Mr. Walsh, during later years, contributed much of his time and scientific and administrative ability, he

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* *Trans.*, xv., 419.

evinced the same personal qualities and powers. The works with which he was connected were among the first to practice the making of glass in gas-heated reverberatories, substituting large hearths for crucibles; and they remained to the last models of modern method and construction.

The following papers were read by title, for subsequent publication and discussion:

Diatom-Earth in Arizona, by William P. Blake, Tucson, Arizona.

The Auditing of a Mining Company's Accounts, by Charles V. Jenkins, Rossland, British Columbia.

Notes on Brazilian Gold Ores, by Orville A. Derby, Sao Paulo, Brazil.

Truck-Support for Furnace-Bottoms, by Henry A. Mather, New York City.

The Camp Bird Mine, Ouray, Colorado, and the Mining and Milling of the Ore, by C. W. Purington, Thos. H. Woods and Godfrey D. Doveton, Ouray, Colo.

Basaltic Zones as Guides to Ore-Deposits in the Cripple Creek District, Colorado, by E. A. Stevens, Victor, Colo.

A Consideration of Igneous Rocks and their Segregation or Differentiation as Related to the Occurrence of Ores, by Josiah Edward Spurr, Constantinople, Turkey.

The Mining Industry of the Cœur d'Alenes, Idaho, by James Ralph Finlay, Colorado Springs, Colo.

The Tombstone, Arizona, Mining District, by John A. Church, New York City.

Notes on the Cost of Hydraulic Mining in California, by W. E. Thorne, Georgetown, Cal.

The Original Southern Limit of the Pennsylvania Anthracite-Beds, by Benjamin Smith Lyman, Philadelphia, Pa.

Determining Size of Hoisting-Plants, by Edward B. Durham, Trenton, N. J.

Further Discussion of Scott's paper on The Evolution of Mine-Surveying Instruments, by E. A. H. Tays and Bennett H. Brough.

A notice of an amendment to the rules was offered as follows:

Rule III., Paragraph III., to read: "Any Member or Asso-

ciate, not in arrears, may become, by the payment of $150.00 at one time, a Life-Member or Life-Associate, and shall not be liable thereafter to any dues."

This amendment changes the amount from $100.00 to $150.00. It will be presented at the annual meeting in February, 1903, for discussion and adoption, subject to a subsequent vote of the members and associates of the Institute by postal ballot.

The Scrutineers, appointed for this purpose under Rule V., reported that the following officers had been elected:

PRESIDENT.

E. E. Olcott, ... New York City.

VICE-PRESIDENTS.

(To serve two years.)

S. F. Emmons, ... Washington, D. C.
James Gayley, ... Pittsburg, Pa.
J. Henry Lee, ... Carbon Hill, Ala.

MANAGERS.

(To serve three years.)

E. W. Parker, ... New York City.
James W. Neill, ... Salt Lake City, Utah.
M. D. Valentine, ... Woodbridge, N. J.

TREASURER.

Theodore D. Rand, ... Philadelphia, Pa.

SECRETARY.

Rossiter W. Raymond, ... New York City.

The session was then adjourned, with the understanding that the meeting would be continued by further sessions at Philadelphia, Pa., in accordance with official notice to be given later.

Proceedings of the Eighty-Second Meeting, Part II., Philadelphia, May, 1902.

Local Committee.—John Birkinbine, *Chairman;* Edward H. Sanborn, *Secretary;* George F. Baer, Cyrus Borgner, Arthur Brock, Theron I. Crane, George C. Davis, James M. Dodge, Theo. N. Ely, E. C. Felton, F. Lynwood Garrison, H. L. Haldeman, E. V. D'Invilliers, Jawood Lukens, E. H. McCullough, Henry G. Morris, Henry G. Morse, T. D. Rand, Percival Roberts, Jr., P. G. Salom, Richard H. Sanders, C. E. Stafford, Henry T. Townsend, S. M. Vauclain, John P. Wetherill, Walter Wood.

Official Headquarters and Bureau of Information.—The Manufacturers' Club, 1409 Walnut Street.

Hotel-Headquarters.—The Hotel Walton, Broad and Locust Streets.

THE first session was held at the Manufacturers' Club on Tuesday afternoon, May 13th. After a brief address of welcome by Mr. Birkinbine, Chairman of the Local Committee, and an appropriate reply by President Olcott, the following paper was presented by title to be read in full at the next meeting.

Biographical Notice of Clarence King, by R. W. Raymond, James T. Gardiner, S. F. Emmons and James D. Hague.

This paper being still incomplete, Dr. Raymond accompanied the reading of the title with remarks and interesting anecdotes concerning Mr. King.

The following papers were presented by their authors, in oral abstract, accompanied with numerous lantern-illustrations:

The Use of Ordinary Cameras in Accurate Photographic Surveying, by Howard W. DuBois, Philadelphia.*

Puddled Iron and Mechanical Means for its Production, by James P. Roe, Pottstown, Pa.

The second session was held Tuesday evening, May 13th, at the same place.

President E. E. Olcott delivered the Presidential Address.

The following paper was presented by the author, in oral abstract, accompanied with numerous lantern-illustrations:

The Cement Industry of the United States, by Richard L. Humphrey, Philadelphia.*

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* Not furnished for publication.

The third session—a joint session of the Institute and the Mining and Metallurgical Section of the Franklin Institute of Philadelphia, Mr. F. Lynwood Garrison, Chairman of the said Section, presiding—was held Wednesday evening, May 14th, at the same place.

The following papers were presented by their authors, in oral abstract, accompanied with numerous lantern-illustrations:*

Presented to this Institute:

The Development of the Bessemer Process for Small Charges, by Bradley Stoughton, Columbia University, New York City.

Presented to the Franklin Institute:

Steel Rails: Relations Between Structure and Durability, by Robert Job, Chemist for the Philadelphia and Reading Railway Company, Reading, Pa.†

The following papers were read by title:

(*For the Franklin Institute.*)

The Beaumont Oil-Field, with Notes on Other Oil-Fields of the Texas Region, by Robert T. Hill, Washington, D. C.

The Metallurgy of Titanium, by Auguste J. Rossi, New York City.

(*For the Institute of Mining Engineers.*)

Growth of the Pig-Iron Production during the Past Thirty Years, by John Birkinbine, Philadelphia, Pa.†

The Effect of Re-Heating Upon the Coarse Structure of Over-Heated Steel, by Karl F. Göransson, Sandviken, Sweden.

The fourth session, held at the Manufacturers' Club, Thursday forenoon, May 15th, was devoted to a discussion of specifications for steel rails, forgings and castings, with reference to papers read at previous sessions, and the following, presented in print on this occasion:

Specifications for Steel Forgings and Steel Castings, by William R. Webster, Philadelphia, Pa.

The Present Situation as to the Specifications for Steel Rails, by William R. Webster, Philadelphia, Pa.

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* By agreement of the two societies, each was authorized to publish, in whole or in part, any of the papers presented to the other society at this session.

† Not furnished for publication.

Remarks were made by Messrs. H. H. Campbell, Robert Job, William R. Webster, C. B. Dudley, William Kent, Gus C. Henning, Prof. G. Lanza and R. W. Raymond.

The fifth and final session was held in Houston Hall, at the University of Pennsylvania, Thursday afternoon. Dr. Edgar F. Smith, Vice-Provost of the University, in a felicitous and interesting address, welcomed the visiting members, and indicated the various departments, museums, etc., of special interest to them, which were open to their inspection. In the absence of President Olcott, Mr. E. V. D'Invilliers, Vice-President of the Institute, made a suitable response, and took the chair for the ensuing session. The following papers were read by their authors, and discussed:

Gold-Mining in McDuffie County, Georgia, by W. H. Fluker, Tatham, Ga.

Principles Controlling the Geologic Deposition of the Hydro-Carbons, by George I. Adams, Washington, D. C.

The following paper was presented in print by the Secretary, in the absence of the author, and discussed:

The Mineral Crest, or the Hydrostatic Level Attained by the Ore-Depositing Solutions in Certain Mining Districts of the Great Salt Lake Basin, by Walter P. Jenney, Salt Lake City, Utah.

The following papers, not mentioned above, were read by title for future publication and discussion:

The Calculation of the Weights of Castings with the Aid of the Planimeter, by Clarence M. Schwerin, New York City.

Silver-Mining and Smelting in Mongolia, by Yang Tsang Woo, Tong Shan, China.

The Gold-Field of the State of Minas Geraes, Brazil, by Herbert Kilburn Scott, London, England.

The Reactions in the Ziervogel Process and their Temperature-Limits, by Robert Henry Bradford, New York City.

The Effect of Tellurium on Brass, by E. S. Sperry, Bridgeport, Conn.

MEMBERS AND ASSOCIATES ELECTED.

The following persons were elected members or associates by postal ballots of January 18, April 2, and April 30, 1902.

HONORARY MEMBERS.

Dimitry Constantine Tschernoff,	St. Petersburg, Russia.
Manuel Maria Contreras,	Mexico City, Mexico.

MEMBERS.

Thomas Adams,	New York City, N. Y.
Harry W. Althouse,	Pottsville, Pa.
Edward Bailey,	Harrisburg, Pa.
Dudley Baird,	Campo Seco, Cal.
James H. Baker,	Steeple Rock, N. M.
José Balta,	Lima, Peru, So. Am.
Henry A. Barren,	Cleveland, Ohio.
J. Mackintosh Bell,	Ottawa, Canada.
John Bermingham, Jr.,	Pinole, Cal.
S. Haldeman Bigler,	Robesonia, Pa.
Thomas O. Bishop,	Wellington, New Zealand.
Edwin W. Bonwick,	Auckland, New Zealand.
Cyrus Borgner,	Philadelphia, Pa.
Anton Bosch,	Berlin, Germany.
Francis W. Bosco,	Denver, Colo.
Herbert Bottomly,	Johannesburg, So. Africa.
James E. Bowden,	Idaho Springs, Colo.
William S. Boyd,	New Castle, New So. Wales.
John Boyt,	La Follette, Tenn.
R. H. Bradford,	New York City.
R. J. Bradley,	Auckland, New Zealand.
Walter W. Bradley,	Robinsons, Cal.
Frederick Bradshaw,	Chihuahua, Mexico.
B. D. Bushnell,	Telluride, Colo.
William A. Caldecott,	Johannesburg, So. Africa.
John R. Carey,	Chihuahua, Mexico.
Wayne Choate,	Detroit, Mich.
Burton I. Collings,	London, England.
Jay A. Czizek,	Salt Lake City, Utah.
Albert C. Dart, Jr.,	Idaho Springs, Colo.
Orville A. Derby,	Sao Paulo, Brazil, So. Am.
Herald Thomas Dickinson,	Kimberley, So. Africa.
Ambrose A. Diehl,	Duquesne, Pa.
Cleveland H. Dodge,	New York City.
Roger H. Downer,	Ouray, Colo.
Gustavus A. Duncan,	Salt Lake City, Utah.
Henry Thomas Durant,	Dayton, Nevada.
William Durbrow,	San Francisco, Cal.
Howard Eckfeldt,	Bethlehem, Pa.
Walter L. Ehrich,	Colorado Springs, Colo.

S. B. Elbert, ...	Idaho Springs, Colo.
Hugh F. Ellard, ...	Ironwood, Mich.
Alan J. Fairbairn, . . .	Denver, Colo.
Wilfrid B. Field, ...	New York City.
Fernando Carlos Fuchs, . .	Lima, Peru, So. America.
Jesus de la Fuente, . . .	Madadores, Coahuila, Mexico.
A. de Gennes, ...	Paris, France.
Henderson Gilbert, . . .	Harrisburg, Pa.
William A. Goodspeed, . .	Longacre, W. Va.
William H. Gregson, . . .	New Castle, New South Wales.
James William Hambleton, .	Mexico City, Mexico.
H. W. Hardinge, . . .	Denver, Colo.
Willard F. Harris, . . .	Ouray, Colo.
W. S. Harvey, ...	Philadelphia, Pa.
J. E. Haverstick, . . .	Philadelphia, Pa.
Frederick W. Hoar, . . .	Globe, Arizona.
F. J. Hobson, ...	Mexico City, Mexico.
James S. Hollings, . . .	Brymbo, North Wales.
Taylor Holt, ...	Sombrerete, Zacatecas, Mexico.
James F. Hopkins, . . .	Parral, Mexico.
Edwin F. Houston, . . .	Philadelphia, Pa.
Charles E. Hulick, . . .	Easton, Pa.
Arthur Curtis James, . . .	New York City.
Frank W. Janes, ...	Melbourne, Australia.
Arthur Jarman, ...	Sydney, New South Wales.
Thomas H. Jenks, . . .	Albuquerque, N. M.
Archibald Johnston, . . .	Bethlehem, Pa.
Waverley Keeling, . . .	Juneau, Alaska.
Alexander G. Keiller, . . .	Denver, Colo.
George A. Kennedy, . . .	Silverton, Colo.
Jeremiah Joseph Kennedy, . .	New York City.
Joseph F. Kent, ...	Horr, Mont.
Austin J. King, ...	Pocahontas, Va.
Simeon T. Kochkine, . . .	Rostow-on-the-Don, So. Russia.
Jerome Baker Landfield, . .	Binghampton, N. Y.
William Lauder, ...	Riddlesburg, Pa.
Alexander Leggat, . . .	Butte, Mont.
Edward M. Lengle, . . .	New York City.
Hamilton Lindsay, . . .	Sault Ste. Marie, Ontario.
Michael E. MacDonald, . .	New York City.
Max McMurray, ...	Cleveland, Ohio.
Herbert H. McNamara, . .	Duluth, Minn.
James S. Mann, ...	Tucson, Arizona.
Herman Mattern, . . .	Hornbrook, Cal.
E. A. Merton, ...	Santiago, Durango, Mexico.
David Irving Miller, . . .	Sheffield, Ala.
Philip Mixsell, ...	Denver, Colo.
Ambrose Monell, ...	Pittsburg, Pa.
Charles R. Murdoch, . . .	Contact, Montana.
Robert Balfour Nicholson, . .	Boulder, West Australia.
Wilton Landis Oglesby, . .	Robinson's, Utah.

Edwin L. Oliver,	Oakland, Cal.
Alexander Orr,	Sydney, New South Wales.
Willard J. Parker,	Mexico City, Mexico.
Frederick M. Passow,	Santa Rita, Mexico.
John C. Percy,	Wheeling, W. Va.
Arthur Philbrick,	Portland, Oregon.
Clement H. Pollen,	Fort Steele, B. C., Canada.
Augustus L. J. Queneau,	New York City.
Ivan Ragaz,	Sierra Mojada, Mexico.
Huntley B. S. Randall,	Monterey, Mexico.
Albert M. Redfearn,	Sultepec-Mexico, Mexico.
Edward J. Roberts,	Spokane, Wash.
Francis W. Scarborough,	Richmond, Va.
F. Schniewind,	New York City.
Herman Otto Schulze,	Rolla, Mo.
Clarence E. Schwartz,	Desloge, Mo.
Linn W. Searles,	La Follette, Tenn.
Joseph B. Settle,	London, England.
William Llewellyn Shaffer,	Idaho Springs, Colo.
Harry J. Sheafe,	Seattle, Wash.
William McG. Shiras,	Pittsburg, Pa.
Frederick S. Shirley,	Buckingham, Queensland, Aust.
Gilbert C. Simpson,	Chihuahua, Mexico.
J. C. Skinner,	Denver, Colo.
George Otis Smith,	Washington, D. C.
Egbert Smit,	Guanajuato, Mexico.
Louis A. Stadtler,	Butte, Mont.
Robert G. Stanley,	New Brighton, N. Y.
Robert Sterling,	Wardner, Idaho.
Gerald B. Street,	Salt Lake City, Utah.
Ernest A. Strout,	Rossland, B. C.
Alan Sullivan,	Port Arthur, Ontario, Canada.
H. N. Tod,	Denver, Colo.
W. H. Tomlinson,	Sault Ste. Marie, Ontario, Can.
John Treweek,	Salt Lake City, Utah.
Nat. Tyler, Jr.,	Washington, D. C.
Titus Ulke,	Sault Ste. Marie, Ontario, Can.
George D. Van Arsdale,	New York City.
Walter H. Virgoe,	Mexico City, Mexico.
H. R. Wagner,	Denver, Colo.
Albert M. Walsh,	Amador City, Cal.
George J. Wanless,	El Paso, Tex.
Bruce R. Warden,	Ferguson, B. C., Canada.
William J. Weatherby,	Cooney, N. M.
Utley Wedge,	New York City.
James Walker Wells,	Belleville, Ontario, Canada.
Shelton King Wheeler,	New York City.
Gordon Wilson,	Mexico City, Mexico.

Associates.

Henry Thornton Bowles,	New York City.
Walter S. Lysle,	New York City.
Reginald Meeks,	New York City.
Myron A. Pattison,	New York City.
James L. Robertson,	Kobe, Japan.
Chas. B. Van Nostrand,	New York City.
L. Webster Wickes,	New York City.
Francis E. Young,	Boston, Mass.

Change of Status, from Associate to Member.

Theodore Dwight,	New York City.
Charles W. Howard, Jr.,	Spenceville, Cal.
L. H. Taylor, Jr.,	Philadelphia, Pa.

Excursions and Entertainments.

The session of Tuesday evening was followed by a "Camp-fire of Veterans," at which Dr. T. M. Drown and Mr. E. C. Pechin gave entertaining reminiscences of the early days of the Institute, and President Olcott, himself a "veteran" (having joined the Institute in 1874), made, upon request, a few remarks concerning the island of Martinique, which he had visited, and the city of St. Pierre, the recent awful destruction of which, by a volcanic eruption from Mt. Pelée, was engrossing the sympathies of all. A most picturesque and pathetic touch in this description deserves to be recorded, namely, Mr. Olcott's mention of the fact that each of the gaily-dressed native women of St. Pierre, in accordance with a sentiment universal among them, wore, in the form of ear-rings or necklace, ornaments of sufficient value to pay for her suitable burial. The contrast between this pious forethought and the tragic death and burial of all these simple daughters of the doomed island needed no comment.

The proceedings of the "Camp-fire" might have lasted much longer, to the interest and profit of the crowded audience, but for the superabundant provision for entertainment made by the Local Committee. It seems to have been expected that, while the "veterans" were talking, the younger members and guests would amuse themselves in the ball-room, or in partaking refreshments. But the young ones liked too well to listen to the old ones; orchestra and ice-cream pleaded, the one melodiously and the other dumbly, but both in vain; and at

last the veterans were forced to adjourn, in order to save the rest of the programme from destruction. However, it is said to be the highest art to stop when everybody wishes to go on; and, measured by this standard, the "Camp-fire" was a triumph of good management.

Wednesday, May 14th, was spent in an excursion to the Edison Cement Works, near Philipsburg, N. J. A special train, furnished by the Pennsylvania R. R. Co., left Philadelphia at 9 A.M., and proceeded, via Trenton and the Belvidere Division, to Philipsburg, where it was transferred to the track of the Delaware, Lackawanna and Western R. R., and hauled to the works of the Cement Company. The plant was not yet in regular operation; but parts of it were operated for the information of the visitors, who inspected with much interest the ingenious and elaborate machinery for crushing, conveying, calcining and handling crude material and product. Refreshments were served in one of the new buildings.

Thursday afternoon, May 15th, before the session, a luncheon was given to the members and guests of the Institute, at the Houston Club, University of Pennsylvania. After the session, the library, museums and laboratories (including especially the engineering laboratory and the new Morgan physical laboratory), the Botanical Garden, Aquaria, and other departments of the University, were inspected with great interest and pleasure.

Thursday evening, May 15th, a reception to the officers, visiting members and guests of the Institute was given by the Local Committee at the Academy of the Fine Arts. The magnificent staircases, halls, rooms and picture-galleries of the Academy are peculiarly adapted for such entertainments; and the occasion, graced by the presence of many eminent representatives of the science and society of Philadelphia (including numerous ladies), was brilliantly picturesque, as well as thoroughly delightful. As may be inferred from the registry given below, the attendance of members and guests, and of the ladies accompanying them, was exceptionally large, and justified, by its numbers, character and cordial enthusiasm, the signal social recognition and entertainment provided in this reception.

Friday was devoted to an excursion on the Delaware river, including visits to the famous ship-yard of the William Cramp

& Sons' Ship- and Engine-Building Co., the new yard and plant of the New York Ship-Building Co., and the League Island U. S. Navy-yard. The intensely interesting nature of these professional inspections was supplemented by a "planked-shad" luncheon at Washington Park, on the Delaware, and the delights of the day were crowned with balmy weather. Indeed, the whole week of the meeting was signally blest in this respect.

Besides the formal excursions and entertainments recorded above, visiting members were, individually and collectively, the recipients of numerous invitations and courtesies from the institutions, clubs, societies, manufacturers and citizens of Philadelphia, which contributed not a little to their comfort and enjoyment.

Members and Guests Registered.

The following persons, together with about one hundred ladies accompanying them, were registered at headquarters:

George I. Adams,	Washington, D. C.
Taylor Alderdice,	Pittsburg, Pa.
Robert Allison,	Port Carbon, Pa.
W. S. Ayres,	Hazleton, Pa.
F. E. Bachman,	Port Henry, N. Y.
Stephen Badlam,	Steelton, Pa.
Geo. F. Baer,	Philadelphia.
B. N. Bailey,	Philadelphia.
Chester S. Batchelder,	Spokane, Wash.
Irving M. Bean,	Milwaukee, Wis.
Lucius S. Bigelow,	New York City.
John Birkinbine,	Philadelphia.
Cyrus Borgner,	Philadelphia.
James Bowron,	Birmingham, Ala.
C. A. Bragg,	Philadelphia.
Samuel D. Bridge,	Monterey, Mex.
Arthur Brock,	Philadelphia.
Albert Broden,	Reading, Pa.
Richard T. Brooks,	Swarthmore, Pa.
Amos P. Brown,	Philadelphia.
Wm. Burnham,	Philadelphia.
H. H. Campbell,	Steelton, Pa.
J. A. Capp,	Schenectady, N. Y.
G. H. Clamer,	Philadelphia.
Edward T. Clymer,	Philadelphia.
William J. Coane,	Philadelphia.
Albert Ladd Colby,	South Bethlehem, Pa.
Verplanck Colvin,	Albany, N. Y.
O. I. Conley,	New York City.

Torbert Coryell,	Lambertville, N. J.
Theron I. Crane,	Philadelphia.
G. C. Crawford,	McKeesport, Pa.
J. D. Darling,	Philadelphia.
George C. Davis,	Philadelphia.
David T. Day,	Washington, D. C.
W. S. De Camp,	New York City.
J. H. Devereux,	Aspen, Colo.
Edward V. D'Invilliers,	Philadelphia.
James M. Dodge,	Philadelphia.
Thomas M. Drown,	South Bethlehem, Pa.
Howard W. DuBois,	Philadelphia.
Charles B. Dudley,	Altoona, Pa.
A. J. Dull,	Harrisburg, Pa.
Edward B. Durham,	Trenton, N. J.
Theodore Dwight,	New York City.
Thomas A. Edison,	Orange, N. J.
A. Eilers,	Brooklyn, N. Y.
Theodore N. Ely,	Philadelphia.
Arthur Henry Eyles,	Addingham, Pa.
Thomas W. Eynon,	Philadelphia.
B. F. Fackenthal, Jr.,	Riegelsville, Pa.
S. E. Fairchild, Jr.,	Philadelphia.
Albert H. Fay,	New York City.
Edgar C. Felton,	Philadelphia.
Thomas Fisher,	Philadelphia.
J. M. Fitzgerald,	Catasauqua, Pa.
W. H. Fluker,	Tatham Mines, Ga.
Stanton S. Freeman,	Parryville, Pa.
Edmund L. French,	Syracuse, N. Y.
F. Lynwood Garrison,	Philadelphia.
Horace L. Haldeman,	Philadelphia.
G. W. Hamilton,	Philadelphia.
Joseph Hartshorne,	Pottstown, Pa.
J. E. Haverstick,	Philadelphia.
G. C. Henning,	New York City.
A. C. Higgins,	Worcester, Mass.
Thos. Hobson,	Philadelphia.
W. Hochschild,	Mexico City, Mexico.
Willard C. Hosbach,	Philadelphia.
Edwin J. Houston,	Philadelphia.
George S. Humphrey,	New York City.
W. S. Hungerford,	Jersey City, N. J.
O. A. Ihlseng,	Carthage, Mo.
Wm. A. Ingham,	Philadelphia.
Walter M. James,	Philadelphia.
George N. Jepson,	Worcester, Mass.
Richard M. Jesup,	New York City.
W. J. Johnston,	New York City.
Washington Jones,	Philadelphia.
F. J. Keeley,	Philadelphia.
H. A. Keller,	San Francisco, Cal.

John S. Kennedy,	Stanhope, N. J.
Julian Kennedy,	Pittsburg, Pa.
William Kent,	Passaic, N. J.
Thos. M. King,	New York City.
Charles Kirchhoff,	New York City.
G. F. Knapp,	Cleveland, Ohio.
Fletcher H. Knight,	Hokendauqua, Pa.
Edward K. Landis,	Philadelphia.
H. M. Lane,	Scranton, Pa.
I. H. Lee,	Baltimore, Md.
N. Lillienberg,	Philadelphia.
John Lilly,	Lambertville, N. J.
E. C. Lindsay,	Philadelphia.
W. W. Lindsay,	Philadelphia.
A. F. Lucas,	Washington, D. C.
A. F. Lucas, Jr.,	Washington, D. C.
Jawood Lukens,	Conshohocken, Pa.
Benj. Smith Lyman,	Philadelphia.
W. H. McCallum,	Philadelphia.
Henry McCormick, Jr.,	Harrisburg, Pa.
A. S. M'Creath,	Harrisburg, Pa.
Leslie M'Creath,	Harrisburg, Pa.
Edmund H. McCullough,	Philadelphia.
John McLeavy,	Punxsutawney, Pa.
Simon S. Martin,	Sparrow's Point, Md.
Chas. A. Matcham,	Allentown, Pa.
E. P. Mathewson,	Montreal, Can.
Chas. C. Mattes,	Scranton, Pa.
W. F. Mattes,	Scranton, Pa.
DeCoursey May,	Philadelphia.
August A. Miller,	Philadelphia.
Fred J. Miller,	New York City.
Robert Mitchell,	Philadelphia.
Richard G. G. Moldenke,	New York City.
A. S. Morris,	Philadelphia.
Henry G. Morris,	Philadelphia.
William H. Morris,	Philadelphia.
Edwin Morrison,	Addingham, Pa.
Henry G. Morse,	Camden, N. J.
Wm. G. Neillson,	Philadelphia.
E. E. Olcott,	New York City.
George Ormrod,	Allentown, Pa.
R. P. Patterson,	Philadelphia.
Edward W. Parker,	New York City.
D. M. Parry,	Indianapolis, Ind.
Edmund C. Pechin,	Torega, Va.
D. D. Pendleton,	Pittsburg, Pa.
Richard Peters, Jr.,	Chester, Pa.
Stephen Minot Pitman,	Providence, R. I.
J. Wesley Pullman,	Philadelphia.
A. Raht,	Salt Lake City, Utah.
Theodore D. Rand,	Radnor, Pa.

R. W. Raymond,	Brooklyn, N. Y.
M. Alton Richards,	South Bethlehem, Pa.
William H. Richmond,	Scranton, Pa.
T. A. Rickard,	Denver, Colo.
Wm. Barrett Ridgley,	Washington, D. C.
C. O. Ripley,	
Percival Roberts, Jr.,	Philadelphia.
James P. Roe,	Pottstown, Pa.
C. W. Roepper,	Philadelphia.
Pedro G. Salom,	Philadelphia.
Edward H. Sanborn,	Philadelphia.
Richard H. Sanders,	Philadelphia.
H. J. Seaman,	Catasauqua, Pa.
Charles Schaffer,	Philadelphia.
E. J. Schmitz,	New York City.
H. H. Seabrooke,	Washington, D. C.
Fred H. Sharpless,	Philadelphia.
J. M. Sherrerd,	High Bridge, N. J.
H. E. Smith,	Milwaukee, Wis.
Oberlin Smith,	Bridgeton, N. J.
Percival H. Smith,	Bridgeton, N. J.
T. Guilford Smith,	Buffalo, N. Y.
George E. Somers,	Bridgeport, Conn.
Erwin S. Sperry,	Bridgeport, Conn.
C. Edward Stafford,	Chester, Pa.
W. M. Stein,	Philadelphia.
Bradley Stoughton,	New York City.
Knox Taylor,	Bound Brook, N. J.
L. H. Taylor, Jr.,	Philadelphia.
W. J. Taylor,	Bound Brook, N. J.
George E. Thackray,	Johnstown, Pa.
Edwin Thomas,	Catasauqua, Pa.
H. G. Torrey,	New York City.
Henry T. Townsend,	Philadelphia.
S. W. Traylor,	New York City.
Samuel M. Vauclain,	Philadelphia.
John A. Walker,	Jersey City, N. J.
Willard P. Ward,	New York City.
Wm. R. Webster,	Philadelphia.
John Price Wetherill,	Philadelphia.
S. Bowman Wheeler,	Philadelphia.
George A. White,	New York City.
Maunsel White,	Bethlehem, Pa.
John F. Wilcox,	Cleveland, O.
William H. Wiley,	New York City.
Oliver Williams,	Catasauqua, Pa.
Frank S. Witherbee,	New York City.
Walter Wood,	Philadelphia.
H. H. Yard,	Philadelphia.
James E. York,	Brooklyn, N. Y.
Frank M. Zeller,	Philadelphia.

Proceedings of the Eighty-Third Meeting, New Haven, October, 1902.

Local Committee.—R. H. Chittenden, Director of the Sheffield Scientific School, *Chairman;* L. V. Pirsson, Professor of Physical Geology, *Secretary;* W. H. Brewer, Professor of Agriculture; C. E. Beecher, Professor of Paleontology; F. L. Bigelow, President of the Bigelow Boiler Works; Theodore A. Blake; Wm. P. Blake, Director of the School of Mines, University of Arizona; G. J. Brush, Professor of Mineralogy, Emeritus; A. J. DuBois, Professor of Civil Engineering; H. W. Farnam, Professor of Political Economy; H. E. Gregory, Assistant Professor of Physiography; J. H. Hammond, Professor of Mining Engineering; C. S. Hastings, Professor of Physics; S. L. Penfield, Professor of Mineralogy; J. K. Punderford, Engineer of the Fair Haven and Westville Electric Railway Co.; C. B. Richards, Professor of Mechanical Engineering; H. B. Sargent, Vice-President of Sargent & Co.; M. F. Tyler, Treasurer of the University; H. L. Wells, Professor of Analytical Chemistry and Metallurgy; Eli Whitney, President of the New Haven Water Co.; H. S. Williams, Professor of Geology.

THE first session was held Tuesday evening, October 14th. Director R. H. Chittenden of the Sheffield Scientific School, as chairman of the Local Committee, called the meeting to order, and, after a few words of greeting, introduced Arthur T. Hadley, LL.D., President of Yale University, who delivered an address of cordial welcome, to which President E. E. Olcott of the Institute made an appropriate reply, making incidental reference to the brief visit of the Institute to New Haven (in connection with the Bridgeport meeting of October, 1894). The Secretary added some reminiscences of the XIIIth meeting of the Institute, held at New Haven in February, 1875, when the library of the Sheffield School was large enough to accommodate the sessions.*

* In view of the lapse of nearly twenty-eight years between the two New Haven meetings, it is interesting to note the important nature of many of the papers presented at the earlier meeting, and the large number of the authors there represented who were present at this meeting, or still survive in active usefulness. For instance, Mr. Olcott, now President of the Institute, then presented an important paper on The Ore-Knob Copper-Mine and the Hunt and Douglas Copper Process; Dr. Raymond, now Secretary, delivered on that occasion the Presidential Address, on the History of the Relative Values of Gold and Silver—a subject destined to become, politically as well as economically, during the two following decades, a "burning question"; Mr. (now Prof.) H. M. Howe read a paper on

A Biographical Notice of Clarence King by R. W. Raymond (assisted by Messrs. S. F. Emmons, James T. Gardiner and James D. Hague) was then read by Dr. Raymond.

The second session was held Wednesday morning, October 15th, when the following papers were presented in print or in printed abstracts:

Notes on the Treatment of Zinc-Precipitate Obtained in Cyaniding New Zealand Ores, by Hamilton Wingate, Bristol, England.

The Direct Cyaniding of Wet-Crushed Ores in New Zealand, by Hamilton Wingate, Bristol, England.

Coking in Bee-Hive Ovens with Reference to Yield, by Charles Catlett, Staunton, Virginia.

Ore-Deposition and Vein-Enrichment by Ascending Hot Waters, by Walter Harvey Weed, Washington, D. C.

Ore-Deposits Near Igneous Contacts, by Walter Harvey Weed, Washington, D. C.

The following paper was presented in oral abstract by the Secretary, in the absence of the author:

The Valuation of Mines of Definite Average Income, by H. D. Hoskold, Buenos Aires, S. A.

Prof. J. A. Holmes, St. Louis, Mo., read a paper on Mines and Metallurgy at the St. Louis World's Fair, 1904.

The following papers were read by title for subsequent publication and discussion:

Blast-Furnace Economy—the first of a long series of contributions to technical literature which reflect credit, not only upon their author, but upon the Institute which constituted from the beginning his appreciative audience; Mr. W. P. Blake (now Director of the School of Mines of the University of Arizona) presented a paper on Provisions for the Health and Comfort of Miners; and George J. Brush, then active and now *Emeritus* Professor of Mineralogy in the Sheffield School, delivered, in the name of that school, the address of welcome to the Institute. All these gentlemen were present in person at this 83d meeting. Among the papers presented in 1875 by persons who still remain among us, having fulfilled in useful lives the promise of their youth, the most important, perhaps, was that of Mr. H. S. Drinker on The Musconetcong Tunnel—out of which paper grew his classic and authoritative imperial octavo on Tunneling. Other important papers were presented by Anton Eilers, Persifor Frazer, E. C. Pechin, Prof. Frederick Prime, Jr., Walter McDermott, and Prof. R. H. Richards. The list of those who contributed to the proceedings of the first New Haven meeting, and have since died, includes the names of Prof. Thomas Egleston, Martin Coryell, Peter Ritter von Tunner, Prof. Henry Wurtz, Gen. Henry Pleasants, Prof. Henry Newton, and J. L. Jernegan. R. W. R.

The Lodes of Cripple Creek, by T. A. Rickard, Denver, Colorado.

The Veins of Boulder and Kalgoorlie, by T. A. Rickard, Denver, Colorado.

The Geology of Southwestern Texas, by E. T. Dumble, Houston, Texas.

The Copper-Deposits of Sierra Oscura, New Mexico, by H. W. Turner, San Francisco, Cal.

Amarillium, by Wm. M. Courtis, Detroit, Mich.

The Manganese Industry of the Department of Panama, Republic of Colombia, by E. G. Williams, Colon, S. A.

An "All-Fire" Method for the Assay of Gold and Silver in Blister-Copper, by Walter G. Perkins, Grand Forks, B. C.

Elimination of Arsenic, Antimony and Bismuth from Copper, by Allan Gibb, Mount Perry, Queensland, Australia.

The Chemistry of Ore-Deposition, by Walter P. Jenney, Salt Lake City, Utah.

The Geological Features of the Gold-Production of North America, by Waldemar Lindgren, Washington, D. C.

Igneous Rocks and Circulating Waters as Factors in Ore-Deposition, by J. F. Kemp, New York City.

The Ore-Deposits of the San Pedro District, New Mexico, by Morrison B. Yung and Richard S. McCaffery, San Pedro, New Mexico.

The third session was held on Wednesday evening, October 15th, when the following papers were presented:

The Development of the Modern By-Product Coke-Oven, by Christopher G. Atwater, New York City (illustrated with lantern-slides).

The Blake Stone- and Ore-Breaker: Its Invention, Forms and Modifications, and its Importance in Engineering Industries, by William P. Blake, Tucson, Arizona.*

* Prof. Blake, who is a nephew of Eli W. Blake, announced at the beginning of this paper the establishment of the "Blake Stone-Breaker Prize," a more detailed account of which is given in the following trust-deed:

"Know all men by these presents, that I, Henry T. Blake, of the City of New Haven and State of Connecticut, representing the heirs of Eli W. Blake, late of said City and State, do hereby transfer, assign and set over to the Board of Trustees of the Sheffield Scientific School certain securities to the amount of six hundred dollars in par value, the said donees and their successors to have and to hold the said securities and their income and the accumulations and re-

The fourth and concluding session was held on Thursday morning, October 16th.

The following paper was read:

An address on The Geology of the New Haven Region, illustrated with lantern-slides, was delivered by Prof. H. E. Gregory, of the Sheffield Scientific School.*

Members and Associates Elected.

The following persons were elected members or associates by postal ballots of August 12 and September 22, 1902, and have formally accepted their election:

Members.

Mason T. Adams,	Linares, Mexico.
Lawrence Addicks,	Perth Amboy, N. J.

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investments thereof in trust for the following uses and purposes and under the following provisions:

"1st. The said Board shall have the charge, custody and control of the property herein donated for the specific object in view, and shall have power to sell and re-invest said property at their discretion.

"2d. Said Board shall use the income of said property from time to time, as said income shall accumulate to a sufficient amount, or so much of said accumulated income as shall be necessary, to confer a money prize—said prize to be known as the Blake Stone-Breaker Prize—of not less than fifty dollars in gold coin, on the author of any treatise deemed worthy of such award on some subject connected with Mining or Civil Engineering, and preferably with some branch of those pursuits in which the use of broken stone or ores is a material feature. In the award of said prize, preference shall be given to the work of students, graduate or undergraduate, in the Sheffield Scientific School of Yale University.

"3d. Said Board shall appoint from the Governing Board of the Sheffield Scientific School three of its members, professors of engineering, who shall recommend the persons upon whom the said prize shall be conferred.

"4th. Said Board shall establish the regulations and conditions concerning the award of said prize, and shall cause a notice of each award to be published among the Transactions of the American Institute of Mining Engineers or in some other leading Industrial Publication.

"5th. In the diploma awarding said prize, suitable reference shall be made by name to the inventor of the Blake Stone-Breaker, Eli Whitney Blake of New Haven, Connecticut, as a memorial to whom this prize is hereby established.

"New Haven, August 1st, 1902.

"Henry T. Blake."

Since the reading of Prof. Blake's paper, the Secretary has received official notice that "The Board of Trustees of the Sheffield Scientific School have made the first award under these regulations, conferring a prize of $50 in gold upon Prof. William P. Blake, for this paper."

* This admirable address, intended chiefly as guide and introduction to the inspection, during the afternoon of the same day, of the geological features which it described and explained, will not be published. R. W. R.

Robert L. Ahles,	Oxford, N. J.
H. S. Badger,	Isaac Harbor, N. S.
Henry Acroyd Barker,	Hedges, Cal.
Felton Bent,	Chester, Pa.
Seymour K. Bradford,	Tonopah, Nevada.
Robert E. Brooke,	Birdsboro, Pa.
Arthur H. Brown,	Dolores, Canada.
Walter S. Brown,	Victor, Colo.
George Tyler Burroughs,	Minidora, Idaho.
James M. Clark,	Kanawha Falls, W. Va.
Harrison Edward Clement,	Bingham Canyon, Utah.
Henry E. Crawford,	New York City.
Clarence M. Dickerson,	La Colorado Sonora, Mex.
Charles W. Dickson,	New York City.
Otto Doeltz,	Clausthal, Germany.
Edgar Satchwell Dorman,	Missoula, Mont.
George H. Duggan,	Sydney, Nova Scotia.
Adolf Ekman,	Oroville, Cal.
Augustus B. Emery,	Rossland, B. C., Canada.
David L. L. Eynon,	Philadelphia, Pa.
Albert Hill Fay,	New York City.
Robert Forrester,	Salt Lake City, Utah.
Floyd J. Foster,	Villadama, Mexico.
Charles D. Garfield,	Juneau, Alaska.
Joseph L. Giroux,	Jerome, Ariz.
Arthur G. Greenameyer,	Leetonia, O.
Frank Wood Griffin,	San Francisco, Cal.
Maurice Edward Griffin,	San Francisco, Cal.
Herbert Haas,	Torreon, Mexico.
W. H. Hackett,	New York City.
Ernest Ames Haggot,	Prescott, Ariz.
Everett J. Hall,	New York City.
Thomas M. Hamilton,	Helena, Mont.
T. F. Hartman,	Boulder, Western Aus.
J. L. Hayward,	Colombia, So. America.
Arthur H. Jameson,	Providence, R. I.
Elias M. Johnson,	Spuyten Duyvil, N. Y.
Owen Johnson,	Smuggler, Colo.
Ralph Ingersoll Johnson,	Denver, Colo.
William A. Kelley,	Denver, Colo.
Waseley A. Kousnetzoff,	Vladivostock, Russia.
Charles Edward Krebs,	Kanawha Falls, W. Va.
Frank Welton Lehmer,	Omaha, Neb.
Henry A. B. Leipner,	Mt. Morgan, Queensland.
N. E. Maccallum,	Phœnixville, Pa.
William Bradford McKinlay,	New York City.
Alfred F. Main,	El Oro, Mexico.
Walter S. Morley,	Berkeley, Cal.
Charles E. Morrison,	Butte, Mont.
David R. Muir,	Kennett, Cal.
James J. Murray,	Keswick, Cal.
Arthur Charles Nahl,	Berkeley, Cal.

John B. Nau,	Canton, O.
Phil. Rudolph de Neufville,	Frankfort, Germany.
George W. Nicolson,	Silverton, Colo.
Edmund D. North,	Los Angeles, Cal.
Tasker Lowndes Oddie,	Tonopah, Nevada.
Ernest V. Orford,	De Lamar, Idaho.
Areli C. Overpeck,	Rapid City, So. Dakota.
Joseph Saxton Pendleton,	Reading, Pa.
John J. Pilgerrin,	Eureka, Utah.
Charles Lawrence Poindexter,	Tombstone, Arizona.
Charles L. Ratliff,	San Pedro, New Mexico.
Stuart Lamar Rawlings,	San Dimas, Mexico.
Charles William Renwick,	Isabella, Tenn.
Motaro Sakikawa,	Niihama, Iyo, Japan.
Rex Robert Seeber,	Painesdale, Mich.
Frederic John Siebert,	Butler, Nevada.
Hoval A. Smith,	Bisbee, Ariz.
Howard D. Smith,	Berkeley, Cal.
H. Staehler,	Halberstadt, Germany.
Dr. Alfred Stansfield,	Montreal, Canada.
William H. Staver,	Freeport, Ill.
James N. Stower,	Plattsburg, N. Y.
Seth Russell Swain,	El Paso, Tex.
Howard H. Utley,	Wilton, Ky.
William E. Wainwright,	Broken Hill, N. S. Wales.
Etheredge Walker,	Gazelle, Cal.
John L. Wentz,	Philadelphia, Pa.
John S. Wentz,	Philadelphia, Pa.
Willis R. Whitney,	Schenectady, N. Y.
Frederick B. Wilder,	Reno, Nev.
David Wilkinson,	Johannesburg, So. Africa.
Henry Ide Willey,	New York City.
Frederick Tuttle Williams,	Victor, Colo.

Associates.

Robert E. Brewer,	Cambridge, Mass.
Harold L. Coombs,	Globe, Ariz.
Arthur Campbell McCallum,	Victoria, B. C., Canada.
Howard Harry Osborn,	Mysore, South India.
Charles O. Ripley,	Newark, N. J.
Aurelio Sandoval,	Nogales, Ariz.
Prospero Sandoval,	Nogales, Ariz.
Philip E. Wright,	Philadelphia, Pa.

Change from Associate to Member.

Walter R. Crane,	Lawrence, Kans.
Howard R. Stewart,	New York City.
William Q. Wright,	San Francisco, Cal.

Change from Life-Member to Life-Associate.

Rev. Richard J. Morris,	Philadelphia, Pa.

Excursions and Entertainments.

At all times during the meeting, the buildings, collections, etc., of the Sheffield Scientific School and other departments of Yale University were open to inspection by the visiting members and guests of the Institute, each of which received also, as a souvenir, a complete illustrated guide to the City and the University, containing much historical, statistical and descriptive information of permanent value, as well as immediate usefulness.

On Wednesday afternoon, October 15th, through the courtesy of the Yale Foot-Ball Association, the visiting members and guests of the Institute enjoyed the spectacle of a foot-ball game between the representatives of Yale University and those of the University of Vermont.

On Thursday afternoon, October 16th, through the courtesy of the Fair Haven and Westville Electric Railway Co., a geological excursion was made to West Rock, where many points of scientific, scenic and historic interest (including, under the last head, the famous "Cave of Regicides") were inspected.

On Thursday evening, a social reception was given by the Local Committee at the Yale Art School.

Friday was occupied by many of the visiting members and guests in more leisurely examination of the University building and collections—especially the Peabody Museum. Prof. S. L. Penfield pointed out objects of special interest in the mineralogical department (comprising the Yale University and Brush collections), and Prof. C. E. Beecher described the exhibition of Dinosaurs and other extinct forms of animal life.

Members and Guests Registered.

The following list (doubtless incomplete) comprises the names actually registered at hotel headquarters, omitting those of about twenty ladies accompanying members:

Lawrence Addicks,	Perth Amboy, N. Y.
Christopher G. Atwater,	New York, N. Y.
Chas. E. Beecher,	New Haven, Conn.
F. L. Bigelow,	New Haven, Conn.
Theo. A. Blake,	New Haven, Conn.
Wm. P. Blake,	Tucson, Ariz.
W. H. Brewer,	New Haven, Conn.
G. J. Brush,	New Haven, Conn.

Irving C. Bull,	New York, N. Y.
R. H. Chittenden,	New Haven, Conn.
W. S. de Camp,	Fulton Chain, N. Y.
Wm. A. Doble,	San Francisco, Cal.
A. J. DuBois,	New Haven, Conn.
Theo. Dwight,	New York, N. Y.
H. W. Farnam,	New Haven, Conn.
Albert H. Fay,	New York, N. Y.
A. W. Fiero,	Chicago, Ill.
W. H. Fluker,	Tatham, Ga.
Henderson Gilbert,	Harrisburg, Pa.
H. E. Gregory,	New Haven, Conn.
Thomas Guffey,	Pittsburg, Pa.
Alfred E. Hammer,	Branford, Conn.
John Hays Hammond,	New York, N. Y.
Dana Harmon,	San Francisco, Cal.
Frank H. Hartung,	Tucson, Ariz.
C. S. Hastings,	New Haven, Conn.
C. W. Hayes,	Washington, D. C.
J. A. Holmes,	St. Louis, Mo.
Henry M. Howe,	New York, N. Y.
W. S. Hungerford,	Jersey City, N. J.
Edwin C. Johnston,	New York, N. Y.
W. J. Johnston,	New York, N. Y.
Julian Kennedy,	Pittsburg, Pa.
Wm. Kent,	New York, N. Y.
P. S. King,	New York, N. Y.
I. N. Knapp,	Philadelphia, Pa.
Robert G. Leckie,	Sudbury, Ont.
J. H. Lee,	Baltimore, Md.
John Lilly,	Lambertville, N. J.
Edwin Ludlow,	Las Esperanzas, Mex.
Lesley McCreath,	Harrisburg, Pa.
E. E. Olcott,	New York, N. Y.
George Ormond,	Allentown, Pa.
E. W. Parker,	New York, N. Y.
S. L. Penfield,	New Haven, Conn.
L. V. Pirsson,	New Haven, Conn.
J. K. Punderford,	New Haven, Conn.
R. W. Raymond,	Brooklyn, N. Y.
C. B. Richards,	New Haven, Conn.
T. A. Rickard,	New York, N. Y.
Chas. O. Ripley,	Newark, N. J.
J. C. Roberts,	Niagara Falls, N. Y.
H. B. Sargent,	New Haven, Conn.
J. M. Sherrerd,	High Bridge, N. J.
Henry Souther,	Hartford, Conn.
E. G. Spilsbury,	Trenton, N. J.
Thos. W. Stiles,	New York, N. Y.
H. H. Stoek,	Scranton, Pa.
Bradley Stoughton,	New York, N. Y.

M. F. Tyler, ...	New Haven, Conn
Leonard Waldo, ...	New York, N. Y.
W. H. Weed, ...	Washington, D. C.
H. L. Wells, ...	New Haven, Conn.
Olaf Wenstrom, ...	Boston, Mass.
Eli Whitney, ...	New Haven, Conn.
E. G. Williams, ...	Colon, Colombia, S. A.
E. H. Williams, ...	Sharon, Pa.
H. S. Williams, ...	New Haven, Conn.

PAPERS.

The Tombstone, Arizona, Mining District.

BY JOHN A. CHURCH, NEW YORK CITY.

(New York and Philadelphia Meeting, February and May, 1902.)

TWENTY years ago Tombstone was the most noted mining camp in Arizona. It presented a combination of fissure-veins and bedded deposits in relations which were most puzzling, and impossible to make out until the extensive development of the mines permitted every detail of the structure to be observed. These details have been studied with great success by W. F. Staunton, now Manager of the Congress mine, in Arizona, and subsequently by H. J. Gray, and the facts upon which the following description is based are mostly the discovery of Mr. Staunton, though confirmed by my own examination.

Tombstone is situated in a country that contains several important mines. On the south, at Bisbee, are the Copper Queen, which Prof. Douglas has described in our *Transactions*,* and other valuable mines; on the east the Commonwealth gold-mine and the recently opened copper-mines at Turquoise, or Gleeson, and the older Middlemarch and Black Diamond. Northeast are the Peabody copper-mines. The wolfram discoveries of two years ago were in the Dragoon mountains, towards which Tombstone looks on the north and east.

Though the town has no railroad at present, it lies but ten miles from Fairbanks, through which place both the Southern Pacific and the El Paso and Southwestern railways run, and it is expected that in a few months a cut-off on the latter road, between Fairbanks and College Peak, passing through Tombstone, will place the camp practically on the main line.

Its general situation is shown in the accompanying map. It lies on the Gadsden Purchase, and is in Cochise county, 25 miles from the Mexican line. The San Pedro river, at Fairbanks and Charleston, afforded an ample supply of water to

* *Trans.*, xxix., 511.

the old mills, and the water-supply of the town is drawn from the Huachuca mountains through a pipe-line about 25 miles long.

Considered as a whole, the formation consists of sedimentary beds in contact with an extensive eruptive mass of granodiorite; but with two exceptions (the Lucky Cuss and Knoxville) the best mines are not near the contact, and the eruptive rock does not underlie the productive part of the measures, unless at a depth greater than 3000 feet.

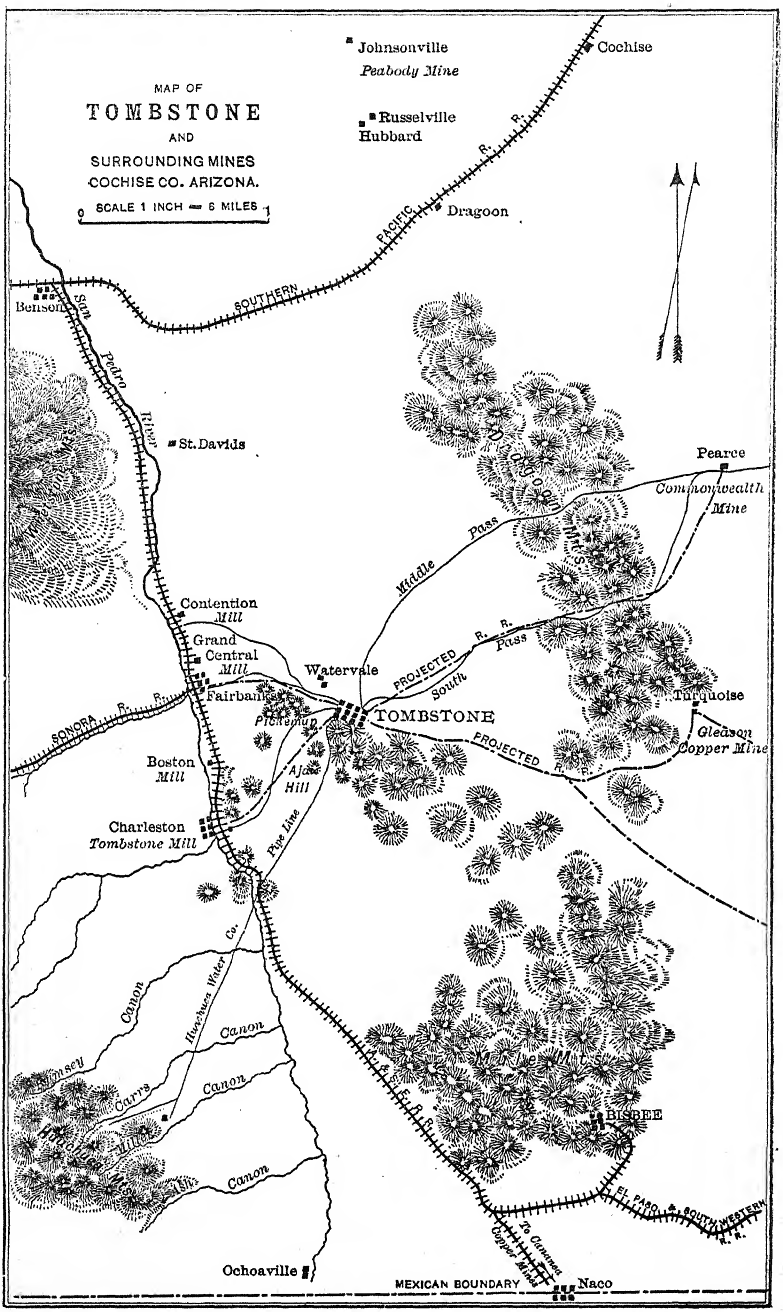
The Lucky Cuss claim has a fissure-vein within 300 or 400 ft. of the granodiorite, and has yielded nearly a million dollars; the West Side, another fissure-vein, is 2000 ft. from the contact, and has produced a million and a half; and the principal fissure of the district, which passes through the Grand Central, Contention and Head Center mines, and has yielded about twelve million dollars, is 4000 ft. from the eruptive rock. A few of the minor bedded deposits are 600 to 900 ft. from the contact, but their total product did not exceed $900,000, while the principal deposits of this type which have produced more than six million dollars are half a mile distant.

In a district like Tombstone, where surface-deposits of small extent have been opened at a great many points, exception can be taken to almost any statement that can be made, on the ground that ore has been found under conditions that do not agree with the general statement; but the preponderance which I have expressed in values could be given also in tonnage, if the books of all the mining companies had recorded the output by weight, and it is clearly shown by the comparative extent and permanence of the stopes and veins. It is by the study of the leading mines that the facts of the formation have been obtained. They show that the deposition of the ore has an intimate and interesting relation to the structure and dynamical history of the sedimentary rocks.

The observable measures of Tombstone consist of 2850 ft. of sedimentary strata, an intrusive mass of granodiorite and a surface-flow of rhyolite.

The Sedimentary Rocks.

At the bottom of the sedimentary series is the Randolph limestone, numbered I. in Fig. 1, so called from the mine of that name in the Charleston side of the district. A thickness


MAP OF
TOMBSTONE
AND
SURROUNDING MINES
COCHISE CO. ARIZONA.
SCALE 1 INCH = 6 MILES
Johnsonville
Peabody Mine
Russelville
Hubbard
Cochise
Dragoon
SOUTHERN PACIFIC R. R.
Benson
San Pedro River
St. Davids
Pearce
Commonwealth Mine
Middle Pass
Contention Mill
Grand Central Mill
Watervale
Fairbanks
PROJECTED R. R.
South Pass
TOMBSTONE
Turquoise
Gleason Copper Mine
SONORA R. R.
Boston Mill
Ajax Hill
Charleston
Tombstone Mill
Pipe Line
PROJECTED R. R.
Huachuca Water Co.
Canon
Carrs
Canon
Canon
Canon
Mule Mts.
BISBEE
EL PASO & SOUTH WESTERN R. R.
To Cananea Copper Mines
Ochoaville
MEXICAN BOUNDARY
Naco

of 300 ft. is allotted to it, as it is certainly more than 200 ft. thick. It has not been an important producer of ore.

Above it is the Ajax quartzite, II., a strong anticlinal in this rock forming Ajax hill, the highest elevation in the district, rising 900 ft. above the town. The Mamie and other mines have been producers from this rock, which is 500 ft. thick.

Over the quartzite is the Emerald limestone, III., 420 ft. thick. About the Emerald, the most important mine in it, this stratum consists of thin limestones interleaved with thinner shales. At other localities it is made up of thicker and purer limestones, with thicker beds of quartzite; but wherever seen it indicates variable conditions of formation. It contains several mines.

Next in the series is the Lucky Cuss limestone, IV., which has several productive mines besides the prominent one that gives it its name. Its thickness is taken at 400 ft., but in the southern part of the district it covers a great extent of country, and undoubtedly thickens rapidly, indicating steady and long continued subsidence. It is often fossiliferous, but metamorphism has made it difficult to obtain satisfactory fossils in any variety. It is full of crinoid fragments and imperfectly exposed corals, the crinoids being most abundant.

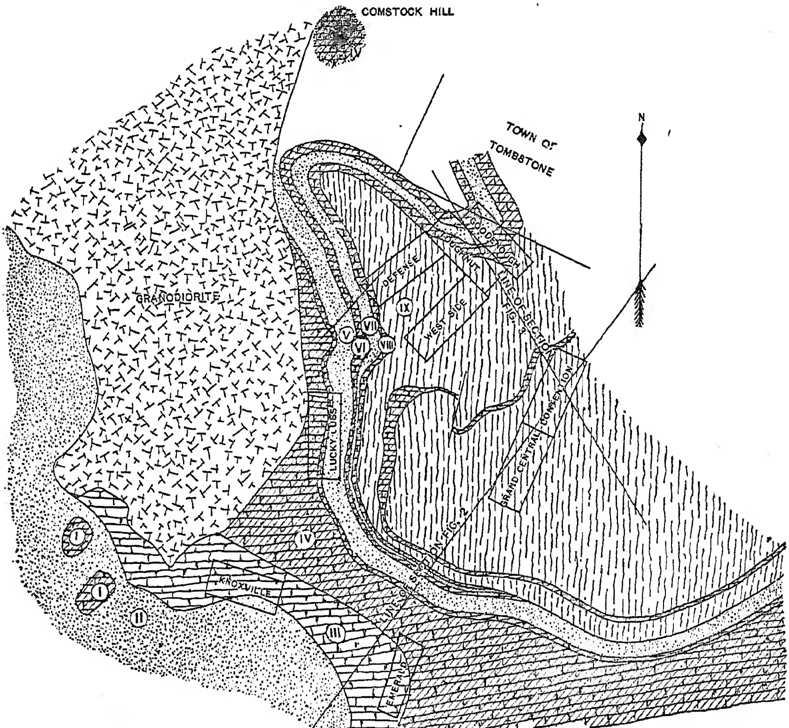
Upon this limestone rests the Herschel quartzite, V., which varies in thickness, but in the section given is taken at 270 ft., a minimum. At the surface it has a shaly structure, but in the East Side crosscut is found to be mostly a dense, fine-grained quartzite.

Above it is the first of the more important ore-strata, the White Lime, VI., 60 ft. thick. This rock, which has produced some of the most valuable ore-bodies in the district, has the usual appearance and softness of pure limestones, but in the ore-bodies and their nighborhood becomes very siliceous—so much so that Prof. Kemp, though deciding it to be limestone, found that the specimen sent him resembled a quartzite with lime intrusions. Its character as a limestone is undoubted; and the siliceous intrusion which characterizes it is probably to be ascribed to the solutions which brought in the ore, for it is not present away from the ore-bodies.

Above the white limestone lies the Toughnut quartzite, VII., 120 to 140 ft. thick. It is one of the three rocks first recog-

nized in Tombstone as belonging to the most prolific ore-measures. It appears to have shared in the silicification due to solfataric action; for, though a quartzite of very fine grain, it gives to one familiar with it the impression of a rock that is not altogether clastic. Prof. Kemp, who examined the rock under the microscope, confirmed this impression, as he reported that, in addition to fragments of quartz, it has much cherty

FIG. 1.



Geological Sketch-Map of Tombstone District, Arizona.

silica, and little veins run all through it. The specimen submitted to him was taken in the heart of the mass, and was not near ore. In the mine it appears a massive, fine-grained rock, but not composed of impalpable siliceous paste, like some of the quartzites in the shales.

This rock sometimes contains ore, but not abundantly. There is one small ore-body in it that seems to be connected

with low vertical stopes in a crevice or crevices, and another that shows some limestone, and may have formed in a limited bed of this rock. Another, which unites the Quarry and Girard anticlinal ore-bodies, lies on the Quarry dike, and extends vertically for 40 ft. There are other small irregular stopes near the same dike. Thus, though ore can make in the quartzite, special preparation seems to be needed for it. Of occurrences where ore makes in it in contact with an ore-body in limestone it is not necessary to speak. Some exceptions occur in all mines.

Over the quartzite is the third of the original ore-series, the Blue Lime, VIII., 90 ft. thick. Unlike the white limestone, this is a soft, deep-blue rock, a typical limestone; and it is remarkable, considering the silica imported into the lower members, that this rock has been unchanged, except in definite lines like veins or in limited areas. In general, the rock is pure.

In the places excepted, there is a dark blue silicified fossiliferous limestone, evidently an alteration of the parent rock, in which no original characteristic except hardness has been disturbed. The blue limestone has been one of the best ore-carriers in the district, as might be expected from its softness and purity.

Finally, we reach the highest stratum with which we have to deal, known in Tombstone as *the* shale, IX., to which I will add the name Contention, as that mine has been the principal producer from it. It contains a heavy bed of quartzite, and many thin limestones and thin quartzites; but the ore-bodies of the fissure-veins go down through all its constituents, and it is sufficient to regard it as a single, though a composite, member. The Grand Central pump-shaft has penetrated it vertically for 681 ft., and is supposed to be still 150 ft. above the blue limestone. It forms the surface over most of the productive area, and its thickness there may be taken as 700 ft.

These four rocks—the shale, blue limestone, quartzite and white limestone—will sometimes be spoken of as the Toughnut series, from the mine where these leading members of the Tombstone formation was first recognized.

The limestones are non-magnesian, and often fetid, even when bleached nearly white.

Few recognizable fossils were found, though all of the limestones are fossiliferous. *Fusulina cylindrica* was found in the

quartzite above the Lucky Cuss limestone and *Spirifer rocky-montanus* in the blue limestone. An undetermined *Chætetes* and a *Productus* were the only other fossils obtained. The indications are that the Tombstone beds belong to the higher measures of the Lower Carboniferous, and, perhaps, to the Carboniferous.

The sedimentary rocks are folded into a synclinal about 4000 ft. wide, measured on the center line of the Toughnut claim, with a nearly east and west axis, which pitches from the granodiorite eastward. The outcrops lie in an irregular horseshoe which has a deformation near the point of the curve that suggests pressure against the granodiorite. They have not been traced beyond a point east of the San Diego mine, but the Lucky Cuss limestone continues there in a line of prominent hills eastward. Except the three Toughnut rocks, this is the only one of the series that can be found near the town—Comstock hill, a mound 100 ft. high, being composed of it.

The composition of these rocks shows that the geologic history of Tombstone was mostly a very quiet one. There are two or three pebbly limestones, and two or three conglomerates with quartz pebbles like walnuts, but nearly all the other rocks are of extremely fine grain. The Ajax quartzite and the thick one included in the shale series are of ordinary visible grain, but the others are mostly of shaly fineness though siliceous in composition. The land mass which furnished the material for these rocks probably lay to the north and west, and sufficiently distant to send only fine sediments to the locality under consideration.

The massive fine-grained quartzites of Tombstone seem to be nearly pure silica, the coarser kinds often containing a large proportion of highly crystalline feldspar, opaque and pink in color. As the quartz grains of the granular quartzites are often perfectly limpid, the combination of these rounded glassy grains with well-developed feldspar makes a product that resembles closely one of the dike eruptives. Other quartzites, less frequently found, have much hornblende. These impure rocks resist erosion better than the pure. Sometimes they have a linear direction like dikes, and I suspect these are to be affiliated with the lines of silicified limestone as a result of the action of hot water or hot gases.

Elevation succeeded the formation of the rocks, and the steep dips in places where it can hardly be attributed to subsequent history indicate that this movement was not insignificant.

The Eruptive Rocks.

The next step in the process of preparing Tombstone for its mineral wealth was the intrusion of an extensive mass of granodiorite. It has a maximum width of about 10,000 ft., and a length of 15,000 from its contacts on the south to the line where it disappears toward the north, under the gravel of the 12-mile-wide valley which separates Tombstone from the Dragoon mountains. It may have some relation to the granitic rock which forms the front of Cochise's stronghold in those mountains, and reaches several miles out in the floor of the valley.

This mass intruded somewhere below the lowest of the known measures, and faulted the rocks at the southern contact, lifting a block from which the sedimentary rocks have been mostly removed by erosion; but patches of them, and in one case a considerable hill, are found scattered over its surface. These patches are mostly limestone which contained a decided proportion of silt, if we may judge from the products of contact-metamorphism. Sometimes quartzite is found, and the composition of these remnants recalls the Randolph and Emerald limestones.

It is evident that the eruptive rock has suffered but little erosion except towards the valley. Near the southern contact it is possible often to walk on the original surface. This fact permits the minimum thickness to be calculated, for the upper surface is now on a level with the Herschel quartzite, and the granodiorite has risen 1600 to 1800 ft. above the level of its entrance, even if it intruded directly under the Randolph limestone.

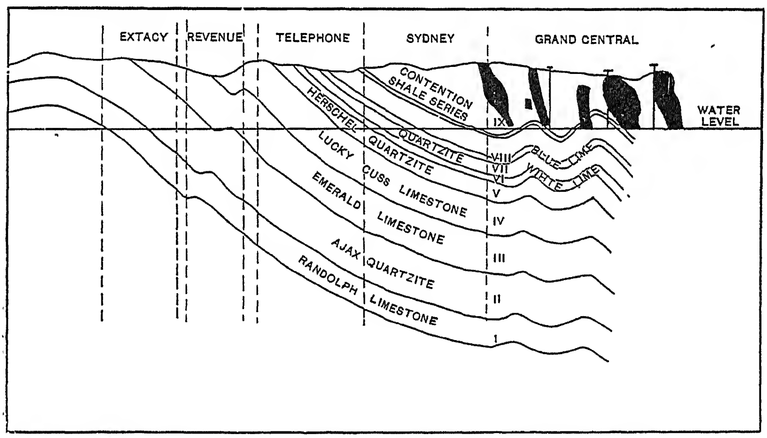
The eastern face of this mass, on which the ore measures abut, is, so far as it can be observed, a sheer fault. At the Lucky Cuss a crosscut on the 140-ft. level reaches the granodiorite at a point vertically under the contact, and on the 340-ft. level a crosscut directly underneath failed to reach the eruptive rock, though pushed nearly to the same distance. The mine is nearly 700 ft. deep, but the dip of the vein takes the openings at the bottom about 600 ft. away from the granodiorite.

Northward from the Lucky Cuss the surface is covered by

gravel, and the eruptive rock is exposed only in gulches on its eastern side; but the conditions indicate that the whole of this side, for a distance of nearly a mile, is a fault-face, and the presence of this vertical face of rigid rock has been one of the factors in Tombstone's history. The western side is also a fault, and abuts on the Ajax quartzite, the width of the block being about 4000 ft., opposite the mines.

The surface-distribution of the rocks in the Tombstone basin is shown in Fig. 1. Fig. 2 is a section taken in a NE.–SW. line through, and nearly parallel to, the Grand Central mine, on a line north of the area where the extreme thickening of the Lucky Cuss limestone begins. The ore-bodies of the

Fig. 2.



NE.–SW. Section on Line Shown in Fig. 1, through Grand Central.

Grand Central are indicated in longitudinal section, to show their position in the so-called shales.

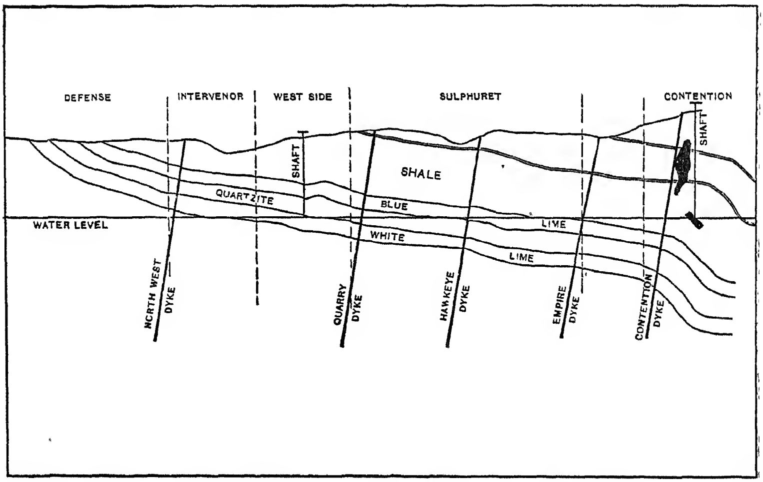
Fig. 3 shows the ore-measures from the outcrop at the town to the Contention mine, being a section taken at right angles to that in Fig. 2. The position of the dikes is indicated, and two of the ore-bodies of the Contention in cross-section. This is the region of the bedded deposits in limestone where the structure is exhibited by extensive mine-openings, and the section is confined to the rocks that outcrop here.

The last addition to the surface-rocks of the district was a flow of rhyolite, which covers an extensive field lying entirely on the Charleston side of the divide which separates that de-

funct town from Tombstone. Not even fragments of it can be found on the surface of the latter's territory. It rests on the Ajax quartzite, at least on its eastern side, and reaches from Ajax hill, which will be found on the map, northwest beyond Fairbanks and southwest to the hills on the San Pedro river, through which the Huachuca pipe-line passes.

Great numbers of dikes are found in the granodiorite, in the sedimentary rocks and in the rhyolite. In the first-named eruptive rock they run in all directions, and are remarkable only for their occasional small size. One of granophyre was

FIG 3.



NW.–SE. Section on Line Shown in Fig. 1.

4 in. thick and 60 ft. long. The sedimentaries are especially rich in dikes at their contact with the granodiorite.

In that part of the sedimentary rocks where the ore-deposits are found the dikes are very regular in strike, parallel, and probably a mile and a half long, and they owe this regularity, probably, to the influence of the fault-face of the granodiorite. The fault runs nearly N., the dikes N. 23° E., dipping W. 80°. Against this fault-face, also, folds of the strata have been developed, whatever beginnings they had before, and the dips are steeper near it than elsewhere.

In the area traversed by the five dikes of the mines there are

none in other directions; but in the Lucky Cuss limestone and eastern part of the basin there are quartz-felsite dikes 150 ft. thick, striking N. 70° E.

The materials of the very thin dikes are always granophyre, usually a pink variety, with well-marked granitic texture, and these are abundant in the granodiorite, as also are dikes, usually much thicker, of a dark granophyre with large feldspars. It is the latter variety which is found exclusively in the dikes of the ore-ground, except one diabase dike in the Northwest and Vizina mines. Several diorite dikes are found in limestone near the contact, and though several feet in thickness, they are often very short. It may be that there is an uneroded portion in the limestone. They are probably a portion of the great eruptive mass in dike form, and have not been found at any great distance from it.

The two varieties of granophyre are not infrequently associated in one dike. The distinction made between them here is due to the absence of the pink variety from the ore-measures. An interesting occurrence of minette in granodiorite near its contact with Lucky Cuss limestone is referred to in connection with the mine of that name. In the rhyolite, dikes of quartz-augite-porphyrite and mica-hornblende-porphyrite were noticed. Erosion, of course, has been strong, for whatever mass was lifted up by the granodiorite has been removed almost completely; and this has been done since the rhyolite eruption, for the summits of that rock now stand 1000 ft. above the granodiorite and within half a mile of it. That flow would certainly have poured into the Tombstone basin, and left its traces there, if it had not been restrained by some lofty barrier.

It is to be hoped the United States Geological Survey will turn its attention to this interesting field, which is too extensive to be studied by private enterprise alone. The formations of the Whetstone, Dragoon and other mountains that encircle Tombstone stand in evident relations with each other and with the developments of eruptive rocks, which form a more extensive series than I have indicated. If properly studied, this would probably be found to be one of the simpler types of structure in Arizona.

Position of the Ore.

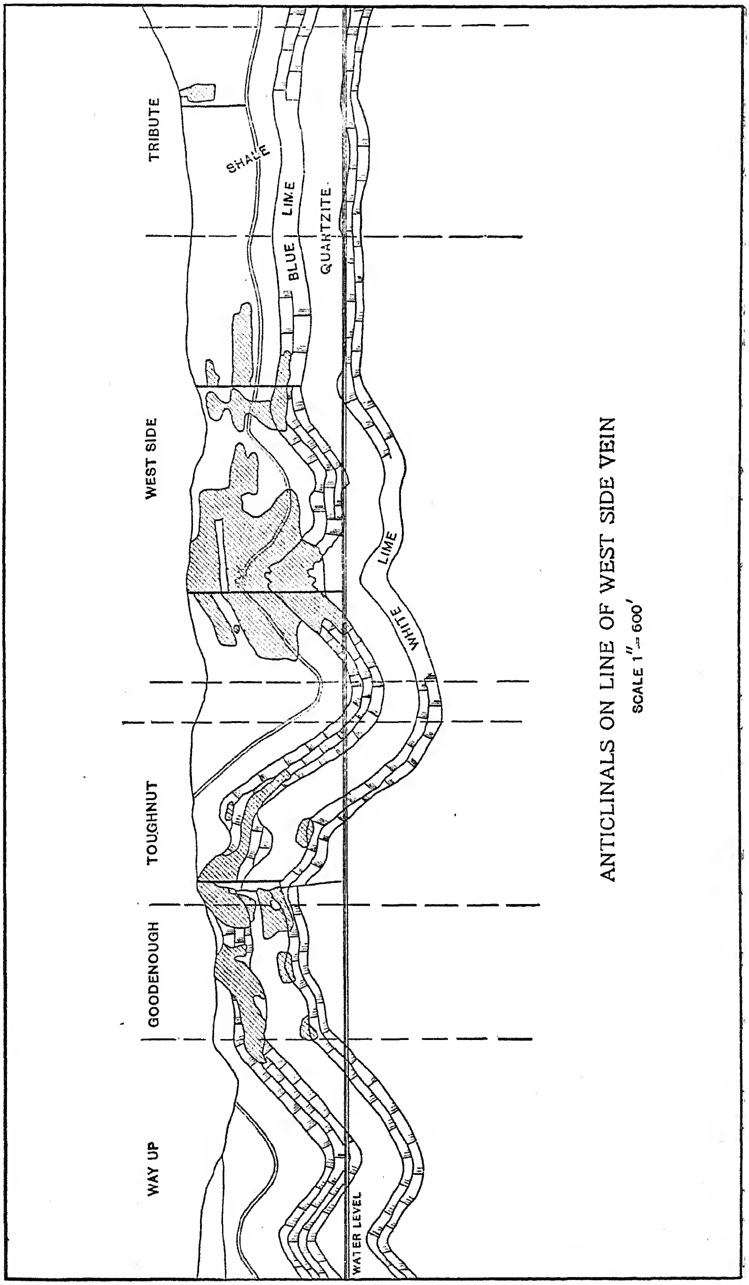
There is nothing in Tombstone that indicates the original seat of the metals which formed the ore; but the structural conditions point strongly to some underlying source from which they have risen, through fissures, to be deposited in the fissures and in strata which had been prepared by folding for the entrance of solutions. The granodiorite has not acted except by its inertness, and the *rôle* of the dikes has been almost equally inferior. The rocks owe their ores almost entirely to the two results of pressure—folding and fissuring.

The folding is in two directions, producing anticlinals, with axes varying in direction from S. 15° E. to S. 65° E. from their outcrops, and monoclinal flexures which lie across the anticlinals. They are usually of gentle slope while the anticlinals are often highly compressed, and, in two or three instances, faulted. The level parts of the monoclinals sometimes rise a little, instead of descending; but the rise is too unimportant to destroy the contrast between the folds in the two directions.

The bedded deposits lie in the anticlinals, sometimes on the flank, sometimes in the apex; but the synclinals are barren. The monoclines do not seem to have limited the deposition of ore, which is found both where they dip strongly and where they are nearly horizontal. The compound surface produced on any stratum by these cross-folds, with their varying direction of axes and steepness of dip, is of unending variety, and undoubtedly has been a controlling factor in the distribution of ore, which is found in all shapes, from long, narrow tongues to broad sheets. There is nothing like the superposed saddle formation, made familiar to us by Rickard and others. In the Goodenough incline, especially, there are as many as three sheets of ore at different levels in the blue limestone, and they coincide vertically for portions of their extent; but they differ in the direction of their axes and dips. The simple anticlinal structure of the saddles is disturbed by the monoclinals.

Fig. 4 shows the anticlinal folding along the line of the West Side vein and across the Toughnut and Goodenough claims where the flat ore-bodies have been most important. It will be seen that there are two principal anticlinals, one in the West Side and one at the Quarry in the Toughnut. On the

Fig. 4.



ANTICLINALS ON LINE OF WEST SIDE VEIN
SCALE 1" = 600'

flanks of these are subordinate folds, which constitute the other anticlinals shown in Fig. 6.

One of the monoclinal flexures across these anticlinals has been plotted in Fig. 5, showing the irregular stopes in the Northwest mine of the Toughnut claim, which have received the name of Hoodoo. On this line there are great numbers of small, vertical crevices, which have sometimes received enough ore to join two overlying bodies together. In the section of this figure the ore-body B occupies the flank of an anticlinal which dips towards the spectator. A and all the others are seen in true section.

Compression-Fissures.

Two lines of vertical fissures are found lying across this system of anticlinals. On one, which has a strike of N. 15° E., the Grand Central, Contention, Head Center and Tranquillity mines are opened, while the other, striking N. 42° E., contains only the West Side mines. Their positions with relation to the anticlinal deposits are shown in Fig. 11.

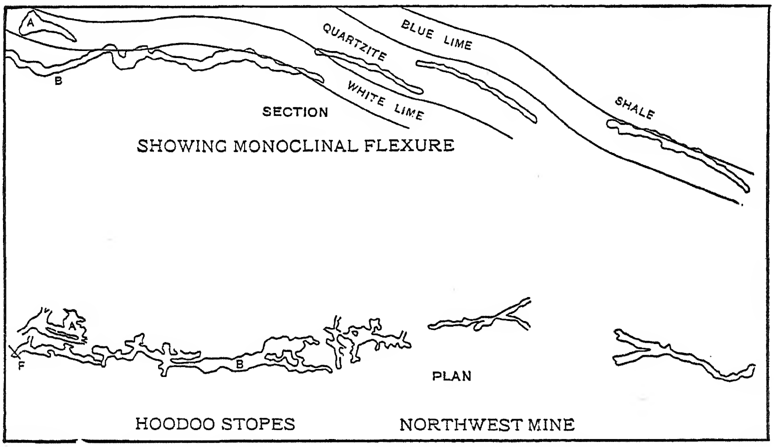
The anticlinals are persistent from their outcrops on the Vizina, Goodenough and Toughnut claims, near the town, to the Contention and Grand Central, and in the fissure-veins we find the distinctive peculiarity of Tombstone, which binds the bedded deposits and fissures in one system. The largest ore-bodies of the fissures are found within the lines of these anticlinals, whether the fissure has been deep enough (as in the West Side mine) to reach the blue and white limes, which are the rocks that contain the bed deposits, or are still in the overlying shale (as in the Contention and Grand Central). The water-level in the last-named two mines is calculated to be 150 ft. above the blue limestone, which contains the highest ore-bodies of the Toughnut series; but the influence of the anticlinals upon the deposition of ore in the fissures is as marked in the overlying shales through which the fissures pass in their upper levels as in the limestones of the bedded deposits.

The second result of dynamic action was the production of these vertical veins, which I regard as compression-fissures. They have been studied most thoroughly in the West Side mine, where the principal ore-body of the fissure was confined to a strongly compressed anticlinal about 450 ft. long. This

fold is succeeded on the north by a broad and barren synclinal and on the south by a narrow synclinal and a gently rising anticlinal. The fissure passes through shale for the first 200 ft. of its depth, and there is a small ore-body within the synclinal in the shale. It does not extend into the blue limestone below, and is probably due to secondary deposition.

There are at least three known parallel fissures within a width of 400 ft. at the West Side, two of which have yielded ore, though the West Side is the only important producer. The walls do not indicate faulting; and though a cross-fault of small throw is observable, it is probably a dislocation of slabs rather than of a section of the country.

FIG. 5.



Plan and Section of Monoclinal Flexure.

In Fig. 4 the ore-bodies shown in the West Side mine are all in the fissure, the anticlinal deposits stretching away from the vein on the side opposite the spectator. The ore-bodies of the Goodenough and Toughnut, on the other hand, are exclusively anticlinal. In order to show the grouping of the ore-bodies on the anticlinal, it was necessary, in a drawing on this scale, to project the flat bodies on their entire dip. The figure is faulty, therefore, in showing the ores of the fissure in section and the ores of the anticlinal in projection. Still, the figure exhibits the anticlinal deposition both in the beds and fissures, and the synclinal barrenness. Of the two ore-bodies in the West Side,

the one lying in the sharp anticlinal is markedly superior, both in size and grade of ore. The inferior one occupies the fissure where it passes through strata of gentle dip, and here there is no deposition along the anticlinal axis, as there is in the sharp fold.

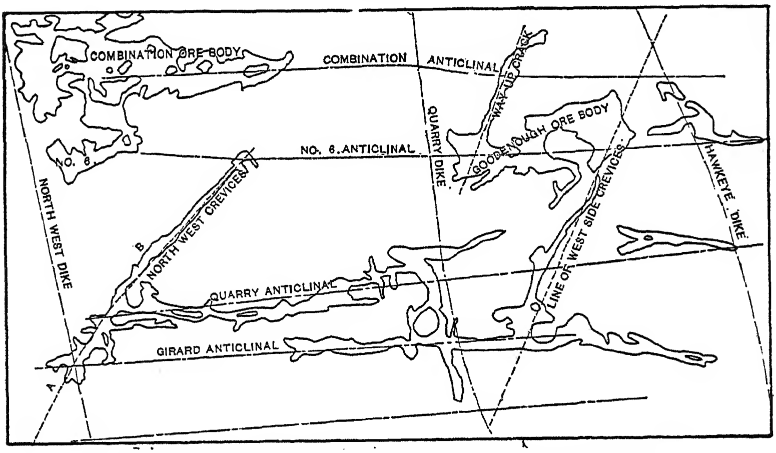
Although the Contention and Grand Central mines are not yet sufficiently cleaned up from the effects of the fires which closed them to permit examination, the extent of their ore-bodies is shown in a report made about 1890, by the late H. G. Howe, who was for many years the leading surveyor at Tombstone. He gives sections of the ore-bodies, reproduced in Fig. 8, which are taken from the south end of the Grand Central to about the center of the Contention. They show very clearly the combination of inclined anticlinal deposits and a vertical vein; and the relation of the two is more striking here than elsewhere in the district, because the two classes of deposits dip in opposite directions—the vertical to the west, the anticlinal to the east.

What is called commonly the Contention vein is a series of nearly vertical ore-bodies which extend northerly through the Grand Central, Contention, Head Center, Tranquillity and Silver Thread claims, a distance of nearly a mile. There was no one continuous vein along this line, but a series of large individual ore-bodies lenticular in cross-section, dipping to the west (with the dike) and pitching to the north. Thus, it is not to be supposed that the upper ore-body in Sec. 3, Fig. 8, has given out abruptly in full width. The figure shows a vertical section through an inclined mass, but the latter did not reach to the next section 320 ft. north.

There were several of these bonanzas in the 400 feet of shales that separate the Contention and Empire dikes, and in the shale east of Contention dike. Mr. Howe says the Grand Central had four "of these chimneys of ore," the Contention three, Head Center one and Tranquillity two. The largest of these is figured in Sec. 4, Fig. 8. Mr. Howe says it outcropped on the surface and extended to the 600-ft. level, pitching to the north; but the section shows that it was formed by three fissures in echelon. On the 300-ft. level it was more than 400 ft. long, and had a maximum width of 30 ft. A hundred feet lower it was 200 by 40 ft. These are large dimensions for so rich an ore. The sections

show that the ore-bodies lay in echelon, several of them appearing in some of the cross-sections, only one in others. It is probable that the parallel crevicing found in the West Side mine is present here also. Three sections show anticlinal deposits. Of that in Sec. 2, Fig. 8, Mr. Howe says: "This ore-body was discovered on the 300-ft. level, and followed up by a raise for 50 ft., where a large body of ore was discovered which lay almost flat; and development also showed that it pitched to the east, and a winze was sunk for 60 or 70 ft., following down upon its dip; but no drift was run along this ore-body at the bottom of the winze, and its extent is not known." No effort was made

Fig. 6.



Subordinate Anticlinals, etc., as Related to Ore-Bodies.

to cross-cut to this ore from lower levels. The three sections showing anticlinal ore-bodies are not successive sections, being separated by two others, in which only vertical bodies are shown. The meaning of this cannot be determined from the old maps, and partly for the reason that the anticlinal ores were not mined or even drifted upon, except one below the water-level, though the grade was good. The "East bodies" shown by Mr. Howe are opposite the anticlinals mined in the Toughnut series further north. The largest of the anticlinals has been followed on ore for 1150 ft. from the West Side vein, or about half the distance to the Contention. The disposition of ore-bodies along anticlinals was not generally known when

Mr. Howe made his sections, and it is probable that the Grand Central and Contention system consisted of nearly vertical ore-bodies along or near the dikes, and of others, more gently inclined, in anticlines crossing from one dike to another and beyond. The west dip of the vertical shoots and the east dip of the flatter deposits is strong evidence of this. The vertical ore-bodies were found in the center of the ground, between the dikes as well as under them.

This series of ore-bodies was the most productive of the Tombstone mines, and the explorations in depth are anticipated with great interest. When the great ore-formations of the district, the blue and white limestones, are reached by the Contention-Grand Central vein in the next 200 to 300 ft., it is expected that the conditions of maximum dynamic effect will coincide with the presence of the most favorable ore-rocks the district has had.

These compression-fissures are one of the most important features of the formation, and have probably been the most prominent factor in the introduction of ore, as the anticlinals have been in its distribution.

Until the Contention and Grand Central are opened sufficiently to allow of careful inspection, it will not be possible to say whether their ore-bodies occupy similar fissures; but the occurrence of ore in the middle ground between the Contention and Empire dikes, which are about 400 ft. apart, leads to the supposition that compression-fissures will be found there. The Head Center fault which cuts the Contention vein and dike is parallel to the West Side fissure.

Nowhere in the district is ore found in the shale except in the fissures, but its presence there proves that this rock was not unfitted for the reception of ore, by whatever method it was formed. The mobility of shale under pressure is supposed to prevent the maintenance even of minute openings, and the general absence of ore from this formation is new evidence of the controlling necessity of crevices as a preparation for ore. In Tombstone there is a contrast between the behavior under pressure of bed-seams and vertical crevices in the shale that is worthy of note. The weight of the rocks, which may not have been more than 500 or 600 ft. thick, was sufficient to close the bed-seams, but not to crush the vertical fissures, and the

delicacy of this difference is shown by the fact that a limestone 2 ft. thick has been mineralized for hundreds of feet on its dip, while the shale in which it is inclosed is barren. If such a stratum is what Mr. Bailey Wills calls "competent" enough to protect and keep open a bed-seam, the pressure of the overlaying rock must have been small.

There is another kind of fracture which is found very abundantly in the blue and white limestones, and to some extent in the Toughnut quartzite, but not in the shale. Cracks of this class occurring in limestone often end abruptly at the contact with quartzite, and I suspect that is the rule, and that these crevices have been produced by a force that affected each stratum of rock for itself, without necessarily producing the same effects in other strata.

Torsion-Cracks.

The most important of these cracks is the Defence vein, which strikes N. 57° E. It is in outcropping blue limestone, and does not enter the underlying quartzite. Another is the Way Up crack, which has most of its length in the Goodenough. Its strike is about N. 65° E. Near it are two minor vertical stopes in the Goodenough incline, one striking E. and the other S. 83° E. On the 200-ft. level of the same mine there is one with strike N. 67° E., which has yielded more ore than any other except the Defence. None of these penetrate the shale, and the few stopes in quartzite nearly on the line of the Way Up crack are close to the Quarry dike, and probably due to its influence. There are some small vertical stopes in the quartzite on the Toughnut claim where the Hoodoo stope enters it; but here, as elsewhere in the quartzite, these crevices are few and insignificant, in comparison to those in the limestones.

The restriction of these crevices to the limestones and quartzite points to an origin different from that of the compression-fissures which penetrate rocks of all kinds and have vertical continuity. I am inclined to ascribe these inferior cracks to the results of torsion accompanying the deformation of the strata by pressure at an acute angle against the granodiorite, the results being produced in each stratum independently of the others. Being confined to the firm rocks, it might be expected that the brittle quartzite would show them most

prominently, which is contrary to the actual conditions; but the quartzite occasionally shows crushed areas where the rock has been broken to a mass of breccia, entirely non-coherent, for several feet in thickness, and these may show how this rock adjusted itself to a strain which made crevices merely in the limestones.

The crevices are most abundant in the area of Fig. 7, and especially toward the Defence vein, which is just outside the figure, below the lower left-hand corner. Fig. 7 is but a poor representation of the number and diversity of strike of those at the northern end of the Hoodoo stopes lying in that quarter. Probably not half of them were noted. Many are barren cracks; others make small vertical stopes confined to one or more layers in the limestone. The crevices here are not long, continuous cracks, though some run for a few hundred feet; and it is noteworthy that these are not the best carriers of ore, probably for the reason that their length and direction take them out of the narrow limits of anticlinal deposition.

Though the Defence vein is in blue limestone exclusively, the crevices shown in the same line in Fig. 7 are in the lower white limestone, the upper stratum being entirely eroded at this point, and they depart strongly from the strike of the Defence, the line curving until it is nearly east and west. Ore has been mined from the outcrop of the overlying quartzite, but it is obviously of secondary origin, and has no continuance in depth.

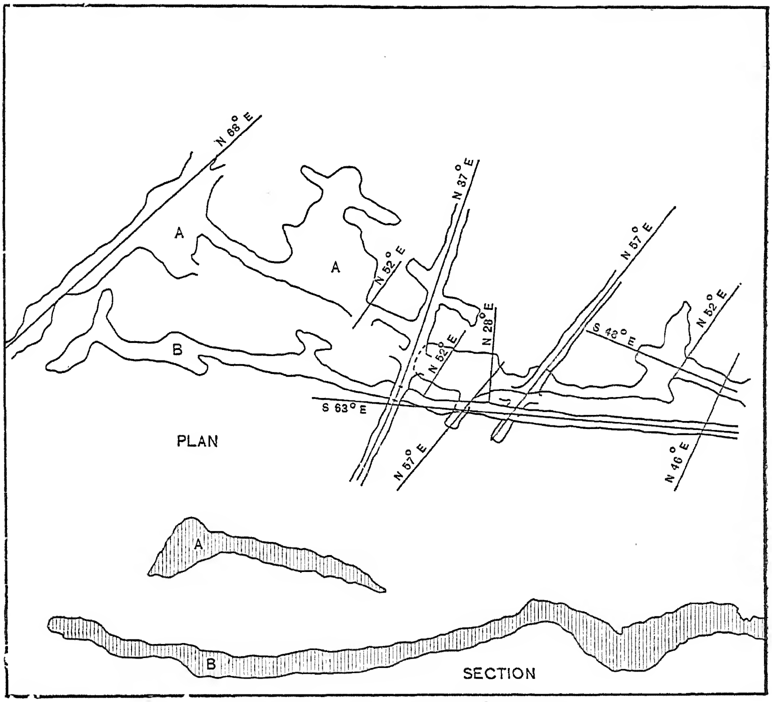
These cracks are found throughout the area of Fig. 7, but they are more abundant near the line of the Defence vein, which is in the area of greatest deformation, and on the line of the West Side fissure, which is 500 ft. or more below the right-hand half of the figure. There is no fissure passing through these places, no continuity in the cracks, parallelism or other connection between them. The whole Defence system belongs to what I will style these torsional crevices, and they are also strongly developed in the line of greatest compression in that neighborhood, the line of the West Side fissure.

Relation of the Dikes to Ore.

The third factor in the forces which have made the Tombstone formation is the series of dikes, the filling of which has

been determined as granophyre and diabase. Nearly all the ore derived from it has been taken from the 2500 ft. of ground lying between the Northwest dike on the west and the Contention dike on the east; but the deposition of ore is not confined to the space included between these two dikes. It has been mined in the Defence 500 feet and in the Ingersoll 1000 feet west of the Northwest dike, and in the Tranquillity some distance east of the Contention dike.

Fig. 7.



Plan and Section of Torsion-Cracks, Northwest Mine.

Fig. 3 shows that one of the principal vertical ore-bodies of the Contention and Grand Central is east of that dike. At least one of the anticlinal ore-bodies in these mines has the same position.

These facts show that the dikes did not have a limiting effect upon the passage of ore solutions. Locally they have modified deposition, but in general their presence was so inert that we must look elsewhere for the controlling factor, and that, as already said, is probably the two results of pressure—folding and

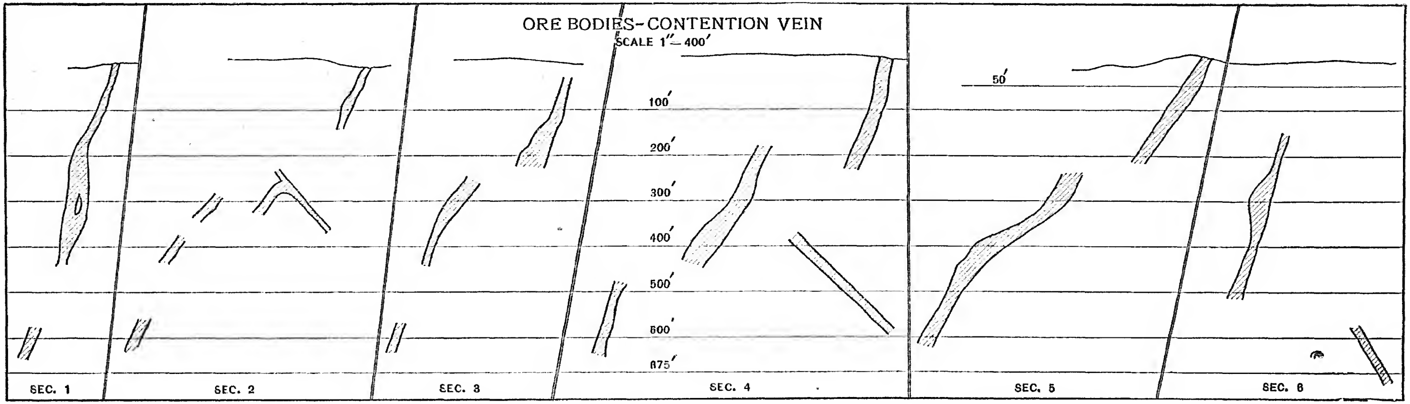
fissuring. All these elements of the problem, except the fissures, are combined in Fig. 6, which shows the ore-bodies (in outline) of the blue and white limestones, the axes of the anticlinals, the directions of some of the crevices, and the positions of the dikes. It shows that along the Quarry dike there is ore connecting the deposits of the Quarry and Girard anticlinals, and that on the Hawkeye dike there is some spreading of the ore in No. 6 anticlinal. The Combination and other ore-bodies begin at the Northwest dike; one small deep-lying ore-body in white limestone ends at the Hawkeye dike. These occurrences are, however, very inferior in importance to the deposition along the crevices and anticlinals.

This figure covers the territory of the Toughnut and Goodenough mines, with a portion of the Hawkeye and Empire. The names given to the different elements of the figure refer, of course, to mines and particular openings in mines. The Northwest and Quarry are both on the Toughnut. Combination, No. 6, Goodenough and Way Up are all on the Goodenough. The crevices are named from the places of their principal development. Each class of occurrences exhibits more or less parallelism in its members, but there is no parallelism between different classes.

In no case that I have found has a dike been a seat of original ore-deposition. The ore-body in the Toughnut quartzite along the Quarry dike is in the slabbed ground by its side, though the dike is thoroughly decomposed. The dikes have been drifted on and cross-cut in the anticlinals, and in all other situations, and the trivial amount of ore they have yielded must be attributed in part to secondary deposition, aided, perhaps, by the quickly diminishing influence of some crevice. In the Contention and Grand Central, where it is probable the deposition of ore has been determined by strong fissuring, the dikes may have been more affected than elsewhere; but all that is known about those mines indicates that their ore-bodies lay near, but not in, dikes.

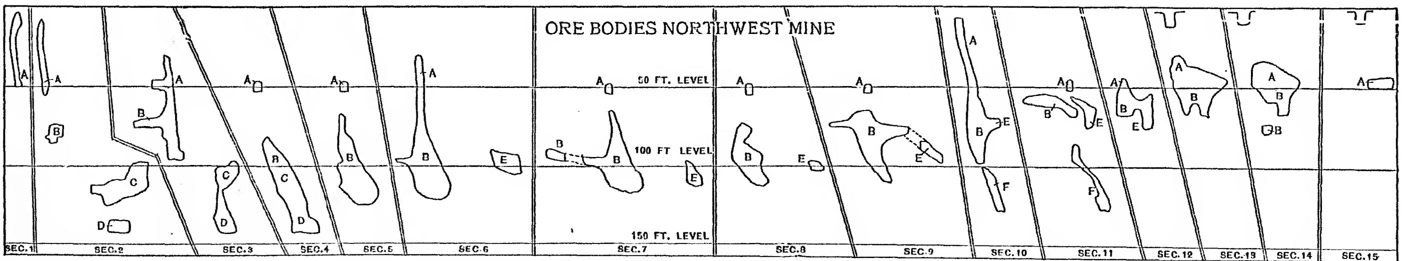
On the surface the dikes often retain their original character unchanged, and their outcrops can be distinguished at a glance. Underground they are completely decomposed, and it is often impossible to distinguish between the rocks derived from them and from the quartzite. On the other hand, in the fissures it

Fig. 8.



Successive Vertical Cross-Sections in Contention Vein, across Line shown in Fig. 1, from S. End of Grand Central to Middle of Contention.

Fig. 9.



Successive Vertical Cross-Sections in Northwest Mine, from A to B, Fig. 6.

is common to find an ordinary appearing quartzite where there should be none of that rock, and with curious frequency the phenomenon is found on one side of the vein and not on the other, though in a few feet more the crossing of a stratum disproves the possibility of faulting. Apparently the vein, before its decomposition, acted as a dam, on one side of which silicification took place, while the other side was free from it.

It is odd that the conditions of dike-decomposition mentioned are not found outside of the especial ore area. The Comet mine has passed through decomposed to unchanged dike in 400 ft. In the granodiorite many of the dikes have suffered so much surface decomposition that they are now oxides of iron, calcite, etc., in a feldspathic magma. They resemble altered limestone, but in a few feet their original texture returns, reversing the conditions found in the Toughnut and Contention.

Ore-Deposition in Limestone.

It is evident that the Tombstone ores are the product of replacement, both in the crevices and the anticlinals. In the latter, especially, alteration-products, of the sort usually found in limestones, are common and are often rich in metals. The capriciousness of the attack of the ore-bearing waters upon the limestone is sometimes extraordinary, especially in the region of torsional fracturing. An example is shown in Fig. 9, Secs. 1 to 15, made from careful measurements of the 50- to 150-ft. ore-body in the Northwest mine on the Toughnut claim, where torsional cracking is especially strong. This body, or series of ore-bodies, extends almost from the surface to near the 150-ft. level, and the sections, taken from A to B, on Fig. 6, cover a length of 250 ft. The ore is entirely in the white limestone, with the overlying quartzite showing in a surface cut in Secs. 13, 14 and 15. The ore-bodies that lie in one vertical plane are enclosed in a panel numbered for each section.

The ore began near the shaft in a vertical fissure which is marked A throughout the series of sections. In Sec. 2 three flat ore-bodies, marked B, C and D, came in below the vertical, and Sec. 3 shows that one of these joins the vertical, which drops down about 40 ft. in a horizontal distance of 15 ft., while the other two stopes have coalesced.

In Sec. 4 the vertical stope has disappeared, and A marks the position of a drift along the crack. Now all three of the

flat stopes have run together, and form an inclined body with a steep dip, but not vertical. In Sec. 5 the vertical comes in again, joining the highest of the three flat stopes in Sec. 2, and in Sec. 6, only 6 ft. distant, the vertical stope has gained no less that 40 ft. in height. Meanwhile the two lower ore-bodies, C and D of Sec. 2, have disappeared, and do not appear again until we reach Sec. 9; but in Sec. 6 a new ore-body, E, comes in, which continues through seven sections. Only one of the flat ore-bodies has marked persistence. B of Sec. 2 continues through a variety of changes to Sec. 14, and it is notable that the whole series begins and ends with the vertical stope A standing alone, though it has frequently disappeared entirely in intermediate sections, and in Sec. 15 looks like a flat stope. In Sec. 10 a new ore-body, F, comes in, which is the beginning of the Hoodoo ore-body along the Quarry anticlinal, Figs. 5 and 6.

A study of these sections shows that there is nothing like a vertical vein in this place. There is verticality in certain stopes along one line for a short distance; but as an ore-body it is fully as irregular as the most variable of the flat stopes, and it is less persistent than one of the latter. It is entirely probable that the vertical arrangement which the flat stopes assume when they coalesce is due to the existence of other cracks in their path. The deposition of ore may have changed from one crack to another, limiting itself to a certain width, within which lie the flat stopes which show by their dip that their shape and position have been determined by the anticlinal folds.

This is well shown in Fig. 5, which is a plan and section of the Hoodoo stope, in the same Northwest mine. Its beginning is the stope F of Secs. 10 and 11, Fig. 9. The position of Sec. 10 is shown on Fig. 5 at F. The strike of these two series of ore-bodies is nearly at right angles. On the lower edge of the plan, Fig. 5, beginning at F, narrow stopes will be noticed following one general horizontal direction. This is the line of the Hoodoo crack, which is ore-bearing only at isolated points. Whether it is one continuous crevice or a series of nearly parallel cracks crossed or touched in slight echelon by the flat stopes cannot be determined. The general conditions of the creviced area incline me to believe that the ore is not always in the same crack. As in Fig. 9, the vertical deposition of ore

is very limited. Besides the Hoodoo crack, there are several others at various angles that show vertical deposition for small heights.

The silicified fossiliferous blue limestone already mentioned is another product of the fissuring, and also of replacement. It is found on the surface and underground in lines of limited length, appearing like veins, and in the mines areas 100 ft. wide have been passed through. They consist of this silicified rock, with scores of open crevices several inches wide. Nothing like this is known in the white limestone. This replacement was not accompanied by metalliferous deposition, except to a feeble extent. Assays of 1 to 3 ounces of silver are sometimes had from the rock, but not always. There is no recognizable relation of this rock to the ore-bodies. It is found both near to and distant from them, and is, perhaps, the only rock in the district that shows no sign of yielding to the influence of secondary deposition. This may be due to the filling of the pores in the original rock by silica before the replacement began.

Some of the thin limestones lying in the shale have been ore-carriers in the vertical veins and anticlines, and the richly mineralized layer which was called the East body of the Contention was probably one of these shale limestones.

Manganese of the Lucky Cuss Mine.

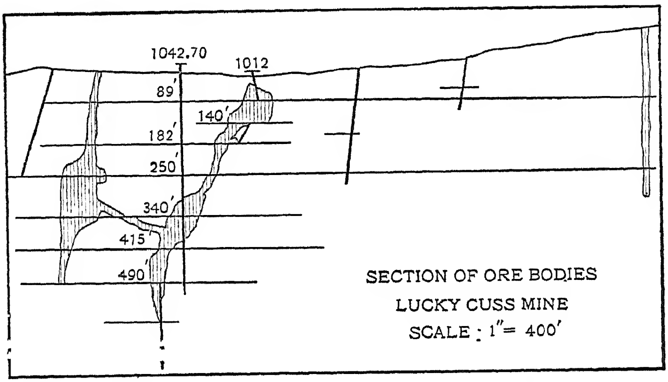
Of the mines in the lower measures, the Lucky Cuss, Fig. 10, is the most interesting. It lies within 400 ft. of the granodiorite, and outcrops about 350 ft. from a dike which Prof. A. A. Julien determined to be a minette, and which lies in the granodiorite close to the contact with limestone. A mass of this rock, 15 ft. thick, encountered below the 350-ft. level, is attributable to an apophyse from the dike. A section from it showed some chlorite, which seems to be absent from the dike. Similar occurrences are found in the Combination ore-body and elsewhere, but none so far from a dike as this.

The Lucky Cuss has had two principal ore-bodies, connected by a cross-shoot at about the fourth level, and several pipes of manganese ore, of which only one is shown in Fig. 10. Most of them are of limited depth; but this one, though otherwise of small dimensions, had a vertical depth of 350 ft.

The origin of the manganese in this mine, and also in the Knoxville and others, is a question of great interest, and was

discussed by C. W. Goodale in a paper before the Institute.* The subject received enlightenment when, under the tongue of minette on the 350-ft. level of the Lucky Cuss, a mass of rock was found which was rich in alabandite, or manganese sulphide, mingled with galena and pyrite. In this position, protected by the dike-rock from the infiltration of surface-waters, the original form of the manganese seems to have been preserved. It is difficult to believe, however, that all the manganese-oxide deposits, which usually form pipes disposed in an erratic manner over the surface of the limestone, represent old deposits of alabandite in place. I am disposed to regard some or all of them as secondary depositions derived from masses or impregnations of the sulphide in the limestone, and prob-

FIG. 10.



ably, in part, from its eroded portion. There is some manganese oxide in all or most of the Tombstone mines, but the quantity is small in the strata above the Lucky Cuss limestone. This and the Emerald limestone produce basic ores wherever opened; but, as Mr. Goodale has pointed out, the true manganese-ores are confined to two localities. The first comprises a series of mines, the Knoxville, Wedge, Lucksure and Lucky Cuss, lying very near the contact of the granodiorite. The second group, containing the Emerald, Bunker Hill, Rattlesnake and Mammoth, is about a mile S. of E. from the contact, and the Comet is still farther away. This group yields basic ore, but the proportion of iron and lime is greater, and of manga-

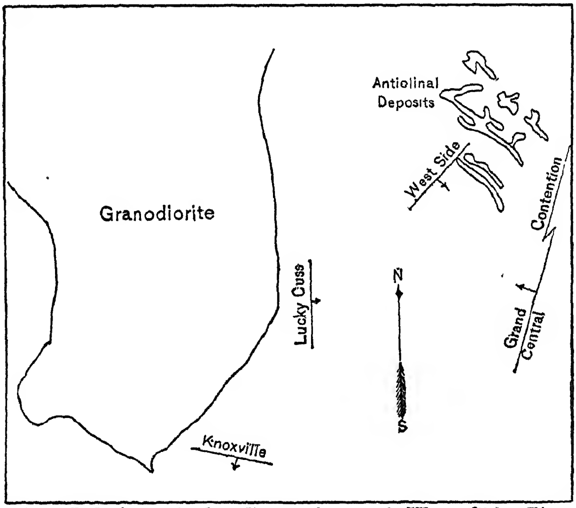
* *Trans.*, xvii., 767, and xviii., 910, with section of ore-bodies.

nese much less, than in the mines near the granodiorite. In both groups the manganese seems to decrease with depth.

The most extensive deposits of manganese are those of the Lucky Cuss and Knoxville. The Lucky Cuss has a fissure with chamber deposits of small extent reaching from it into the limestone walls. The Knoxville is described by Mr. Goodale as a series of four ore-shoots lying in the line of a continuous closed crack. The relation of these two mines to the granodiorite is shown in Fig. 11.

The distinctive manganese deposits are the only ones in the

FIG. 11.



Plan, Showing Relation of the Contention and West Side Fissures to the Anticlinal Deposits, and of the Lucky Cuss and Knoxville Mines to the Granodiorite.

district that indicate by their position an intimate connection with the granodiorite. The mines in the Randolph limestone, which also yield a basic and somewhat manganiferous ore, are about 3000 ft. from the contact. The presence of alabandite under an apophyse which is derived from a dike in the granodiorite, and the occurrence of the Comet ore under a granophyre dike, are indications that the entrance of manganese did not follow immediately upon the intrusion of granodiorite. It must therefore be ascribed to aqueous deposition. There is strong evidence that the bodies of oxide are depositions from solutions, but it cannot be determined whether they always oc-

cupy the position of original sulphide bodies, which they have enlarged, or have sometimes entered barren cracks and replaced the limestone walls. The Lucky Cuss ore, which was so rich at the surface that slags made from it contained 43 per cent. MnO, gradually lost manganese and gained silica and lead. This vein undoubtedly received large accessions of oxide as a secondary deposition. Something of the same kind seems to have taken place in the Knoxville, where, Mr. Goodale says, the ore-pipes had a siliceous center, surrounded by a richly manganiferous shell next the limestone.

All the manganese-ores were very poor in gold at the surface, and I believe the Knoxville did not change; but the Lucky Cuss improved so much that the ore below the water-level contained $12 per ton of this metal. The alabandite of the Lucky Cuss was not a solid mass of that mineral, but a local enrichment of the sulphides of manganese, lead and iron, the greater portion of the mass being silica and limestone, though there were masses of the manganese sulphide several hundred pounds in weight.

The Comet mine, the largest of the manganese deposits, is an instance of the wide extent of ore-deposition in the district, lying 2200 ft. east of the Grand Central. Active deposition has taken place over an area in the Tombstone basin about 10,000 ft. long from north to south and 7500 ft. from east to west. This does not include the mines on the Charleston slope.

The Comet vein lies under and in contact with a granophyre dike 60 ft. thick, and has been mined for a length of 2000 ft., and to the 400-ft. level. Its ore is valuable for its fluxing quality, besides the silver.

Mines in the Rhyolite.

A mine of great interest from its position in the rhyolite is the State of Maine. The rhyolite on the side nearest Tombstone is poured out on the Ajax quartzite. In the State of Maine there are two nearly parallel veins in the rhyolite which reach down to the underlying quartzite, 375 ft. deep on the inclination of the shaft and 240 ft. vertically. The quartzite has been cracked by the heat to a shaly condition, or at this point one of those changes of composition which are frequent and sudden in this district may have occurred.

The sedimentary rocks are folded, and at one point appear

to be broken. It is possible that the rhyolite takes the form of a dike there, about 60 ft. thick, but the question cannot be determined until greater depth is reached or the rhyolite is crosscut. The veins are from 2 to 7 ft. thick, and quite irregular in strike, so that they come to a junction with an angle between them of 20°. When parallel they are about 50 ft. apart, and both dip NW. 45°. These interesting veins have been very profitable for the amount of metal they have yielded, which was probably $600,000. The mine is not now in condition for proper examination, but the stopes resemble strongly those in limestone. The hanging is a smooth continuous wall of rhyolite, the veins very soft and decomposed, and apparently they carried ore in individual ore-bodies rather than a continuous vein. Their average strike is N. 35° E., and dip of the incline 40° N. 55° W. The dip varies from about 33° to 48°, with much larger variations for short distances. The ore was manganiferous and rich in silver.

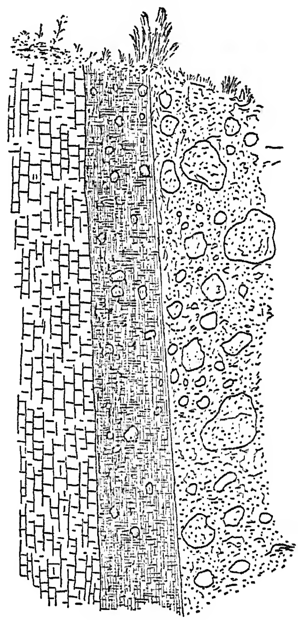
There are many other openings in the rhyolite, and the mineralization of this rock appears to have been quite extensive, though the number of profitable mines was small. The Maine was the most successful, and the San Pedro, near it, probably stands next in productiveness. The Bronco, near Charleston, 7 miles away, is in siliceous schists, entirely surrounded by rhyolite. It is the oldest mine in all this region, having been a developed property before the outcrops of Tombstone were found. It has had a most checkered history, and is now worked with more vigor than ever before. In general, I believe the veins in the rhyolite have had rich ore, but have been small and irregular.

Faults.

One of the curiosities of Tombstone is a fault in Emerald gulch with shale on one side and caliche on the other. Its strike is N. 32° E., dip E. 80°. A shaft in it is 20 ft. deep, without disclosing the full extent of the throw. This interesting fault is shown in Fig. 12. It is marked by the usual zone of laminated or crushed material, which contains both caliche and shale fragments. As the caliche is entirely a product of local erosion and modern calcareous cementing, and must have been formed since the time of powerful erosion, this fault, which seems to be equal in throw to others in the district, must be quite recent.

On the hill back of the Grand Central mine there is an open crevice which is said to have opened, or at least enlarged, within recent years. It is therefore commonly attributed to the caving of the stopes in that mine, its strike, N. 32° E., being about the same as that of the ore-bodies. The explanation is not satisfactory, for the thickness of rock between it and the stopes would, in this locality of shaly quartzites, be sufficient to fill the widest stopes of the Grand Central without producing any effect upon the surface. The parallelism between this open fissure and the caliche fault is suggestive. They are about 3000 ft. apart, the crack being nearly due north from the fault.

FIG. 12.



Fault between Shale and Caliche in Emerald Gulch.

There are several faults in the district, but none of moment. The largest vertical fault known is in the Empire part of No. 6 anticlinal, 50 ft. The Quarry anticlinal is faulted 35 ft. Of cross-faults, the best known is on the Contention-Head Center line, where the dike and vein have been shifted 120 ft. horizontally. There is also a small horizontal throw of 20 ft. in the Empire dike, and others noticeable in the outcrops of the shale limestones. The anticlinal faulting preceded the deposition of ore. In the Empire there is ore under the shale on the upthrow side, but none on the downthrow side. In the Quarry fault there is ore on both sides, but here we have not only one of the strongest anticlinals in the district, but a dike just through the outcrop. There is no sign of an ore-body faulted after its deposition. The dikes do not seem to have caused faulting, no instance of it being known. The torsion-crevices, on the contrary, frequently faulted the ground. In the Hoodoo stopes there is occasionally a jumble of limestone and quartzite blocks, but with small throw. The Head-Center fault is interesting because it is

closely parallel to the West Side compression-fissure and crosses the Contention vein at an angle of 30°.

With this example of faulting in a crevice, it is somewhat remarkable that the West Side fissure shows no faulting, but abundant disproof of it. There is some slipping of slabs on each other, but very little, and the bedding-lines across the drifts prove that there has been no general movement. The West Side and Contention represent the strong lines of compression-fissuring, and no faulting along their lines is known.

Ratio of Gold and Silver.

The entire yield of Tombstone is estimated at 163,000 ounces of gold, 21,500,000 ounces of silver, and 5000 tons of lead. The losses by pan-amalgamation, which was the method by which most of the product was obtained, would require an addition of 15 per cent. to the gold and silver to obtain the gross total of these metals, making somewhat more than 187,000 oz. gold, and 22,500,000 oz. silver. The proportion of gold was, therefore, only 0.827 of one per cent., by weight, of the precious metals.

The total value of all products as marketed was about $25,000,000, to which about $4,000,000 must be added for losses, and somewhat for unreported product. Some mines report only their net returns, leaving the expenses of marketing to be surmised, though they belong to the net yield.

The mines varied extremely in their proportions of gold and silver. The Contention and Grand Central produced about 20 gold to 80 silver, by value, which corresponds to about 1 ounce gold to 80 ounces silver, as the latter metal was worth about $1 at that time. Other mines show a much smaller proportion, the Tombstone Mill and Mining Company having 1 gold to 180 silver, and in mines which were confined entirely to superficial deposits in limestone the proportions may have fallen to 1 : 400 by weight.

The relative proportions of gold and silver in the ore forms one of the most interesting and important problems of the district, and there are indications that a favorable change is taking place with depth. The gold value was greater in the fissure-veins than in the anticlinal deposits, and it improved in both going downward.

In the Contention, a drift run for a length of 140 ft. about

90 ft. below the water-level gave an average assay of more than $100 per ton in gold, and this was in an anticlinal deposit. The condition in the vertical bodies is not reported. In the West Side the ore found at the lowest points mined in the anticlinal, 1150 ft. from the vertical vein, yielded $17.20 per ton as the average of 55 shipments, which is probably four times the average of the West Side vein near the surface.

The same increase is found in both vertical and flat deposits. The Lucky Cuss, which had little more than a trace at the surface, produced ore worth $12 a ton below the water-level, and the last two shipments contained 1.7 ounces, or $35 a ton. The lowest ore of No. 6 anticlinal yielded 1.63 ounces, or $33.58 per ton, as the average of 71 shipments. The ore now mined in the Tranquillity is also rich in gold.

While these are merely specific instances, we obtain from the books of the Tombstone Mill and Mining Company a comparison of the product by periods, which is more exact and also more instructive. From June, 1879, to March, 1884, inclusive, that company produced 10,931 ounces of gold and 3,459,555 ounces of silver, or 1 : 317. From March, 1884, to December, 1893, the product was 26,745 ounces gold and 3,247,603 ounces silver, or 1 : 121, the proportion being 2.6 times as high in the second period as in the first. The only mine opened from the grass roots in the second period was the Lucky Cuss. All others were opened in the first period, and had their deep mining in the second period. This company mined two fissures and nearly all the anticlinals in the camp, and its results must be received as representative of the true conditions in the district. This increase of gold with depth is as interesting in a scientific sense as it is important to the future prosperity of the district.

If I understand Prof. Comstock* correctly, he ascribes this increase in gold tenure to impregnation following an ancient uplift and folding, which was succeeded by a later uplift that brought in silver, the latter being geologically higher than the ores of the first deposition.

Confining myself to this district, without considering evidence to be obtained from other districts in Arizona, I do not find facts at Tombstone to sustain his view. There have been two well-marked periods of folding there. One preceded the

* "The Geology and Vein-Phenomena of Arizona," *Trans.*, xxx., 1038.

intrusion of the granodiorite; the other came after the intrusion, and crowded the strata against the eruptive mass, producing effects strongly marked in its neighborhood; but I see no evidence of different ore-depositions after these events. The entrance of all the ore was later than the second folding. The difference of level in the Goodenough incline between the poorer gold-ores of the surface and the richer of the Empire is less than 300 ft., the continuity of the ore is complete, and the ore itself is as uniform in character as oxidized ores ever are.

Roughly speaking, about half the gold and silver produced in Tombstone has been taken from the upper shales, about a third from the blue and white limes, and most of the remainder from the Lucky Cuss limestone at various points of its extensive outcrop. The quartzites over and under the white lime have carried the least ore, but neither of them has been reached in the larger fissure-veins which have had richly paying ground in the quartzite included in the upper shale. The Toughnut quartzite was ore-bearing in the West Side mine.

The town of Tombstone occupies a flat gravel mesa, or table, quite level for a width of a third of a mile from north to south, and sloping gently to the west for a mile and a half. The gravel lies on the anticlinal shown on the extreme left of Fig. 4, and the white limestone of Combination and No. 6 anticlinals outcrops on the southern side of the town. Toughnut gulch is a natural boundary on that side, and, with the exception of Comstock hill, the rock exposures stop at the gulch. Some do not reach it, being covered by gravel. To the north is a waste of gravel, which a shaft near the town penetrated for 300 ft. without reaching rock.

After lying idle for several years, the reopening of the Tombstone mines has been undertaken by gentlemen who were prominent in the early mining of the district. A new shaft, with two hoisting compartments 4 by 7 ft. and two pump compartments 5 ft. 9 in. by 7 ft., has been sunk near the Contention fissure, and has reached the water-level at a depth of 569 ft. This work was done and the shaft strongly timbered in less than five months. Pumps to throw 1750 gallons a minute will be installed. It may seem remarkable that pumps of such capacity should be needed in a region that is not only

arid, but one where the underlying rocks receive an unusually small part of the rain that falls. The caliche which Prof. Blake described in a recent paper* covers a large part of the district and sheds the surface-water, and the run-off is abnormally large. The calculations are made on the results of pumping done in 1884, when about 1,500,000 gallons a day were thrown out. The water has never returned to its old level by 6 or more feet; and, though there is a great body of water in the ground, it is believed that, when once removed, the rocks will be permanently dry.

The water-level on the west side of the granodiorite is about 250 ft. higher than on the Tombstone side, which may indicate a great depth of rhyolite between the mines there and the San Pedro river, 6 miles distant and 400 ft. lower.

One of the principal objects of my examination of the Tombstone district was to ascertain what measures are likely to be encountered below the water-level. The presence of the "granite" formerly led to the supposition that it underlaid the town and ore-bearing rocks; but the evidence contradicts that impression. The mines still have about 2000 ft. of known sedimentary rocks under them, and perhaps much more.

The revival of these mines is a matter of more than usual interest, for it is based upon convictions derived from a knowledge of the structural geology of the district, and this knowledge is in no sense a theory nor an ordinary scientific explanation of facts. The mines in the anticlinals were managed for years in the light of this knowledge, and thousands of feet of drifting was done to reach anticlinals at the contacts of their rocks. The work began on a theory of Mr. Staunton's, but repeated successes soon lifted it from the plane of reasoning to the solid basis of experience.

It is this experience which will guide operations in future, and the projectors have the greatest faith in their successful outcome. All the fissure-veins, all the most productive mines in anticlinals, and many of second importance, have been consolidated in one ownership, as was necessary before a company could be formed to pay for draining the entire district.

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* *Trans.*, xxxi., 220.

Diatom-Earth in Arizona.

BY W. P. BLAKE, F.G.S., DIRECTOR OF THE ARIZONA SCHOOL OF MINES, TUCSON, ARIZONA.

(New York and Philadelphia Meeting, February and May, 1902.)

General Description.

Forty-five years have passed since I discovered the extensive and remarkable diatom-earth beds at Monterey, California, and now I have the satisfaction of bringing to notice still another wonderful deposit in the heart of Arizona. The Monterey beds were described at the Philadelphia Academy,* and specimens were sent to Prof. J. W. Bailey, West Point, N. Y., at that time the leading American authority upon such microscopic relics of organic life.

The earth from both localities is snow-white and pulverulent. It rubs off like soft chalk upon the fingers when handled, and has the general appearance of chalk. But, unlike the Monterey beds, these newly-discovered deposits consist largely of volcanic ash, through which the siliceous shells of the diatoms are distributed.

These deposits are in the central portion of the San Pedro valley,† in the southeastern corner of Pinal county. The region of their greatest development is a few miles south of the mining town of Mammoth, on the east bank of the stream, and near Redington, some 40 m. N. of Benson, on the Southern Pacific railway. The altitude is about 2600 ft. above tide. This portion of the San Pedro valley lies between the high Catalina and Rincon ranges on the west and the Galiuro mts. on the east. The Catalinas are composed chiefly of crystalline

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* *Proc. Phila. Acad. Nat. Sci.*, vol. vii., p. 328 (1854–55); also, *Report Geol. Reconn. in California in* 1853 (4to., 1855; and in *Pac. RR. Surv.*, vol. v.).

† The Rio San Pedro of the early explorers and fathers is the Rio Quiburi of the aborigines. The valley was explored in 1697 by two Spanish parties, united for the purpose, and accompanied by 30 Indian auxiliaries. They marched down the river to the Gila, and thence to Casa Grande, returning up the Santa Cruz. (See *Bancroft's History*, vol. xvii., p. 355.)

and gneissic rocks, and the Galiuros of rhyolite and volcanic tufas. Both ranges are flanked by broad slopes and accumulations of detrital materials, covering an older series of horizontal deposits, apparently of lacustrine origin, which are exposed in the eroded channels of the river and its chief lateral tributaries. At times of heavy rain-fall, the "wash" from the mountains often reaches the center of the valley, and overwhelms the bottom-lands and cultivated areas with a destructive avalanche of boulders, gravel and sand.

The diatomite beds are horizontal; do not appear to have suffered any disturbance since their deposition; and form the almost vertical walls of the chief lateral cañons, attracting the eye by their snowy whiteness, especially where any recent excavation or falling down of the cliff exposes a fresh surface. Dust and disintegration clouds the surface somewhat; but the beds are always distinct in appearance from the red clays above and below them.

No distinct planes of deposition or stratification appear; and the specimens collected give no evidence to the eye of the existence of layers of stratification. They show a uniform white surface. But when the deposit is seen *en masse* in the arroyos and bluffs along the cañons, a difference in hardness, and probably in fineness, is shown by the unequal weathering. Evidently some of the beds are softer than others, and yield more readily to erosion, thus disclosing a straticulate structure otherwise obscure. The lower portions of the deposit appear to be coarser than the upper layers, and to have more distinct partings of thin layers of clay; but these partings are not numerous.

It is not easy to determine the total thickness of the deposit, since there does not appear to be any place where it is exposed in a continuous series from top to bottom. It disappears under the bottom of the cañon; and the upper surface appears to have been considerably worn away. The greatest thickness noted from the floor of the cañon to the top of the beds was estimated at 100 ft. This includes argillaceous beds at the base, and a few feet of superficial wash-gravel at the top. The beds in which the relics of the diatoms most abound are not less than 25 ft. thick.

Blocks of seemingly homogeneous snow-white diatomite can

be quarried out, though the unweathered beds are somewhat tough. It can be easily cut up into slabs with a saw or knife. It is light and porous. Several blocks cut as nearly as possible into one-inch cubes were found to average 221 grains, or 14.335 grammes in weight, and to absorb as much as 75 per cent. of their weight of water. When wet, the material loses its whiteness and assumes a mottled greenish-gray color.

These determinations were made upon specimens from one of the lower and coarser layers.

Although to the unaided eye there is no apparent difference in the size of the particles from the different levels, all the specimens being white and soft, yet the touch reveals some coarser grains; and particles of grit are found when a block is cut by a saw, and there is evidently a considerable difference in the degrees of fineness at different levels. By brushing the surface with a soft brush, the finer particles are gradually removed, and the coarser are left standing in relief, palpable to the touch and visible through a pocket-lens.

Under the microscope, the material is seen to consist, for the most part, of nearly colorless vitreous particles. It is apparently a volcanic ash or dust—or, rather, a comminuted volcanic glass—in minute transparent angular flakes, generally not more than 0.1 mm., but ranging from 0.1 down to 0.005 mm., and averaging, perhaps, about 0.05 mm. in diameter. Here and there in the mass, as spread out in the field of the microscope, appear particles, showing brown or dark-green color by transmitted light. These may be bits of obsidian, or possibly augite or hornblende. Since they can be readily concentrated by levigation, they are clearly heavier than the colorless glass-like particles. There are also small scales, apparently of a silvery mica.

Palæontological Determinations.

In the midst of the finely divided vitreous particles, the higher powers of the microscope bring into view the beautiful forms of the siliceous remains of diatoms.

Full suites of samples of this new deposit have been sent to eminent specialists, amongst them Dr. D. B. Ward, of Poughkeepsie, N. Y., Dr. Arthur M. Edwards, of New Jersey, and Mr. C. L. Peticolas, of Richmond, Va., all of whom express great interest in the material, and find in it many new forms.

The Monterey deposit Dr. Edwards declares to be marine,* and similar in most of its characters to the celebrated stratum underlying the city of Richmond, Virginia.

In June, 1899, Mr. C. L. Peticolas, of Richmond, Va., wrote acknowledging the receipt of samples, and saying that they contained some undescribed forms and interesting variations from well-known ores; also, that the earth resembled, in difficulty of treatment, certain apparently similar earths "from the far East, which have been subjected to volcanic disturbances, and are probably mixed with sulphate of lime."† In another place he said: "I have a sample from a deposit (recent) from Mobile bay which resembles that from Arizona."

Chemical Composition.

A chemical examination shows that the white earthy portions are chiefly silica with water, alumina, and a little lime. Carbonic acid is not present. A quantitative analysis by Mr. H. A. Mann, Assistant in the Laboratory of the Arizona School of Mines, gave the following results:

	Per cent.
Loss by ignition, chiefly water,	5.07
Insoluble (SiO_2),	82.81
Iron oxide,‡	1.10
Alumina,	4.84
Sodium chloride,	0.45
Calcium oxide,	2.10
Magnesia,	trace.
Organic matter undetermined,	
	96.37

The loss by ignition varies in different samples. One determination gave as little as 3.43 per cent.

The analysis of the Richmond, Va., diatomite showed the presence of 8.37 per cent. of moisture, 75.86 of silica, and 9.88 of alumina. The diatomite of Storey county, Nevada (presumably the so-called "electro-silicon"), showed the presence of 18.44 per cent. of water (lost at red heat), 81.08 of silica, and no alumina.§

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* *Amer. Jour. Sci.*, xlii. (Nov., 1891), p. 383.

† As to this observation, it is fair to say that tests of my Arizona material fail to show any sulphate of lime.

‡ Determined as metallic iron and calculated as Fe_2O_3.

§ *Report of the Eleventh Census of the U. S.*—"Mineral Industries," p. 708.

In the upper portion of a part of the Arizona deposit there is a siliceous layer of light olive-green opaline silica, very compact and dense, occurring in the midst of the white earth very much as flint occurs in chalk. It is nodular in form, and very irregular in its thickness. Upon ignition at a red heat, it gives off water and loses 5.7 per cent. of its weight. Specific gravity, 2.08. It breaks with a conchoidal fracture, and is translucent on the thin edges. Before the blowpipe it blackens, and gives off an empyreumatic bituminous or smoky odor, indicative of organic matter. It decrepitates explosively, and, when heated to redness with access of air, gradually assumes a red color, due, no doubt, to the oxidation of the ferrous to ferric iron.

Diatoms a Possible Source of Petroleum.

The occurrence in this deposit of diatoms of compact vitreous hydrous silica (opal-silica) is the more interesting, inasmuch as layers of similar silica occur in the great diatomite beds at Monterey, and other points along the coast of California. I found there several layers of such silica, and noted also the fact that they were bituminous, yielding bitumen, as well as water, by distillation in a tube.* Other compact siliceous masses of a darker color, thrown up by the waves on the beach at San Pedro, were recognized as bituminous and infusorial in origin, and as indicative of a submarine development of beds like those at Monterey.† The possible diatomitic origin of bitumen and petroleum was thus suggested. The idea receives support and confirmation by the recent discovery of petroleum in globules in the substance of diatoms at a locality in Texas, described by Dr. Phillips, the Director of the Texas Geological Survey.‡

Samples of marine ooze, collected off the Sabine Pass, generally showed the presence both of living diatoms and empty shells. In one sample, a large number of living diatoms were found. These were mainly of one species of *Navicula*, with one of *Pleurosigma*. Both of the species contained relatively large globules of oil in their plasma. These oil-globules, espe-

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* *Report of a Geological Reconnaissance in California* (W. P. Blake, 4to, 1855), pp. 178–179. † *Ibid.*, pp. 181–182.

‡ "Texas Petroleum," by Wm. Battle Phillips, Ph.D. *Bull. No.* 5 *of the Univ. of Tex.* (1901), pp. 20–28.

cially abundant in the *Navicula*, were of various sizes and irregularly distributed throughout the body of the diatom. Mr. Wm. W. H. Long, Jr., who made the microscopical examination and a report, says: "On the death of the diatom the oil-globules seem to separate from the other contents of the shell, and finally to pass out of it."

Referring to the experiments of Kraemer and Spilker, and to the extraction by them of a brownish-black wax-like mass, together with sulphur, from peat, Dr. Phillips observes:

> "It shows that the power of certain diatoms to secrete oil is clearly allied with the power to secrete organic compounds of sulphur; the sulphur and the oil being present together. Furthermore, this power of selective absorption of oil and sulphur by these diatoms may be compared with the absorption of nitrogen and nitrogenous compounds by *bacilli* attached to the roots of certain plants, such as clover, peas, etc. In the case of the fixation of nitrogen by *bacilli*, we have one of the most beautiful illustrations of the power of obscure forms of life to influence vegetable growth, and even to condition it. In the case of the diatoms which absorb oil and sulphur compounds we have a fruitful suggestion of the origin of petroleum and its association with sulphur."

Lacustrine Origin.

The lacustrine origin of the Arizona diatomite deposits is shown by the diatoms and the fineness of the volcanic ash, proving the absence of strong currents and the existence of quiet and deep water. The thickness of these beds of extremely fine materials indicates also a long period of quiescence, and the absence of floods of muddy water. It is scarcely conceivable that such accumulations of clean, white volcanic ash could have been made by the transporting power of water; for currents which could have carried the ash could at the same time have carried considerable fine clay. Moreover, the material would have undergone a sorting action, to which it does not appear to have been subjected. Heavy and light particles are intermingled, though easily separable by slight washing.

The source of the ash must have been eolian. There must have been copious and long-continued showers of volcanic ashes, to form a deposit of such great extent and thickness. I have elsewhere noticed the evidences of lacustrine conditions along the San Pedro valley, and stated the probability that the extensive red-clay-deposits were laid down in a lake, or in a nearly land-locked estuary far in the interior, remote from

active tidal action. In such an estuary there would be a mingling of salt and fresh water, permitting such a mingling of salt- and fresh-water forms as we find in the deposits.

If this is the correct view of the former conditions, the drainage of the valley, as of other nearly parallel valleys in Arizona, was the result of a general or epirogenic elevation in the late Tertiary or Quaternary, such as drained the great interior valley of California.

Other Localities of Volcanic Ash with Diatoms.

For a description of extensive beds of volcanic ash over a wide area, reference may be made to a paper by E. H. Barbour,* who describes beds in Wyoming, Nebraska and Kansas, several feet in thickness, containing also diatom-frustules and sponge-spicules. These beds underlie the loess, and extend throughout the Miocene (Oligocene) up to, and through, the Loup Fork beds.

The material is white and fine in texture, and is used locally for polishing purposes, and as a scouring-soap, or as a substitute for pumice. The figures given by Mr. Barbour show that the forms of the particles are like those of the Arizona deposits, being sharp, angular, flake-like chips, generally less than one millimeter in diameter.

Thick beds of soft, white diatomite are quarried in Nevada, near the old road from Carson to Virginia City.

Extensive beds, occurring in Alaska, have been noted by Schwatka, McConnell and Russell. The ash on the Upper White river has been specially studied by Dawson† and Hayes.‡ The latter estimates the area of distribution of the tufaceous ash to be more than 52,000 sq. m. The greatest thickness observed was between 75 and 100 ft. Brooks§ found this white volcanic ash on the White river, where a bed a few inches thick was overlain by 6 in. of soil. On the Snag river he found a thickness of 3 feet. He describes the material as a finely-comminuted white ash, seemingly made up entirely of vol-

* Rothwell's *Mineral Industry*, vol. vi., p. 22.

† "Report on an Exploration in the Yukon District," *Geol. and Nat. Hist. Survey of Canada*, vol. iii., Part I., Report B (1887).

‡ "An Expedition through the Yukon District," *Natl. Geog. Mag.*, iv., 147.

§ "Reconnaissance in the Tanana and White River Basins, Alaska, in 1898," by Alfred Hulse Brooks, *U. S. Geol. Sur.*, *Twentieth Ann. Rept.*, Part VII., p. 475.

canic glass. The coarsest grains varied from 0.5 to 1 mm. in diameter.

USES AND VALUE.

Diatomite and the associated volcanic ash have a variety of economic uses. Diatomite (known also as infusorial earth, or diatomaceous earth, and by the Germans as *kieselguhr*) is usually classed among the abrasives, such as tripoli, rotten-stone, etc. It is largely used as a polishing-powder. The white earth from near Carson, Nevada, sold under the trade-name of "Electro-Silicon," is an example. The Arizona earth, if cleaned by elutriation from coarser materials, such as grit and the larger flakes of volcanic glass, makes an excellent polishing-powder for metals, including silver.

Its use in the manufacture of dynamite as an absorbent or "dope" for nitro-glycerine is well-known. It has been successfully employed as a non-conductor of heat for coating steam-pipes and boilers; and could doubtless be used to advantage in the manufacture of safes. It is applied in coating steam-pipes by the California Anti-Caloric Co., and is valued for that market at $9 per ton on the surface at the mine, and $18 per ton at the works in San Francisco. In 1897, a deposit was opened at Lompoc, Cal., and about 500 tons were shipped from there.*

The production of diatomite in the U. S. ranges in the neighborhood of 3000 tons annually.

SECRETARY'S NOTE.—For more exact and detailed paleontological descriptions, with figures by Dr. Ward, etc., the reader may be referred to a paper by Prof. Blake, about to be published (June, 1902) in the *Transactions* of the Wisconsin Academy of Sciences.—R. W. R.

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* *Mineral Industry*, vol. vi., p. 16.

The Mineral Crest, or the Hydrostatic Level Attained by the Ore-Depositing Solutions, in Certain Mining Districts of the Great Salt Lake Basin.

BY WALTER P. JENNEY, E.M., PH.D., SALT LAKE CITY, UTAH.

(New York and Philadelphia Meeting, February and May, 1902.)

In the limestone area of Tintic and other mining districts of the Great Basin region of Utah, it has been observed that surface-outcrops of ore occur but seldom, and are mainly confined to points of relatively low elevation, where the veins cross some basin or ravine. Nowhere does a considerable body of ore outcrop on the tops or high up on the slopes of the hills.

Mining operations, on the other hand, have shown that large and continuous ore-deposits frequently occur in depth in the limestone, beneath large masses of barren rock. Such ore-bodies, when followed upward in the lodes, are found to terminate at well-defined levels, without reaching the surface. Yet the minerals-bearing fissures themselves extend above the top of the ore, being often traceable, though barren of all valuable minerals, for hundreds of feet above the stopes in the mines, and even observable in outcrops in the surface.

This abrupt cessation of the ore at a uniform horizon does not appear to be connected with any change in the country-rock adjacent to the lodes. The strata above and below this horizon seem to be in every way equally favorable to ore-deposition. Explorations above it have developed an open-fissured country, barren not only of ore, but also of indications that minerals bearing gold, silver, lead or copper were ever deposited in the strata at that elevation.

The height reached by the ore, while usually constant throughout the length of a given lode, may vary in particular sections, from the operation of local causes. Each lode in a district has its own distinct horizon, above which the ore-deposits do not extend. Where the ore-bodies are continuous

for a long distance on the strike, and other conditions are uniform, the top or apex of the ore is nearly level or gently undulating; but more commonly its upper surface is broken into a series of peaks and pinnacles, alternating with flat summits and wave-like crests, reaching up from the main ore-channel to practically the same relative altitude, and forming the ore-crest or mineral crest of the lode.

Examination discloses in these mines many evidences that the terminal edge of the ore nearest to the surface represents, substantially, the height to which the mineral-depositing solutions ascended in the fissures during the period of ore-formation; in other words, that the present ore-crest is the high-water mark, or ultimate level, reached as the result of the ascensional force of the heated ore-bearing waters.

In some instances, lines of extinct mineral-vents, nearly over the ore-bodies, on the surface, mark the course of the lode. These are small local outcrops of quartz, chalcedony, siderite, ankerite, barite, and other gangue-minerals, seldom carrying more than traces of the precious metals. It is not improbable that, during the period of ore-deposition, these vents were geyser-like pipes or channels, extending from the ore-deposits, hundreds of feet below, up through the non-mineralized strata to the surface, and constituting points of escape for steam and gases liberated by the chemical reactions incident to the formation of the ore. Surface-explorations of some of them indicate that they were channels of up-flow for the waste waters expelled by the pressure of the steam and gases, after the deposition of the ores in the deeper strata. Among other evidence supporting this view is the occurrence in thick, banded sheets, lining crevices and open channels in these outcrops, of white, translucent chalcedony, a mineral deposited by hot silica-bearing waters.

To better understand these peculiar phenomena, it is necessary to consider the conditions attendent upon their formation. The earlier volcanic disturbances of the region are regarded as the direct cause of the elevation of the districts and the upturning of the sedimentary rocks, producing the numerous small mountain ranges and solitary island-like upheavals which illustrate the varied types of the Basin Range structure.*

* See "Lake Bonneville," by G. K. Gilbert, and others, *Monograph* I. (1890); also other monographs of the U. S. Geological Survey.

These earlier disturbances were followed by a long period of comparative rest, during which a wet climate prevailed and an extensive erosion of the exposed strata occurred, carving the surface of the districts to nearly their present contour. There were the same low mountain ranges, with spurs projecting like promontories into the sands of the desert, their steep slopes deep-cut by narrow, rocky ravines, or scooped out in basin-formed gulches.

Later disturbances, deep-seated in the earth's crust, formed the vein-fissures and induced the deposition of the ores, at a time when the topography of many of these mining districts varied little from the present surface. The recent erosion, which has taken place since the deposition of the ores, has probably not removed, even on the more exposed slopes, more than 100 to 200 or 300 ft. in depth of rock-surface. This preservation of the ancient topography has been due, in great part, to the change in climate. In the present extremely dry period, surface-erosion is reduced to a minimum. So little are the outcrops of the ore-bodies eroded, that the conclusion seems inevitable that the present arid climate has prevailed continuously since their formation.

In such districts, the outcrop, or intersection of the vein-fissures with the old surface-erosion, would be, in profile, an irregularly broken or serrated line, rising from the lowest points, where the fissures crossed some deep ravine or basin, to summits where the fissure-belt cut through the tops of the hills or divides. Under these conditions, the mineral solutions, forced upward in the fissures, found outlets of escape at places of relatively low elevation along their course, with a consequent reduction of head or hydrostatic pressure so great that, no matter how open the fissures, or how favorable the ground, no considerable deposits of ore could be formed above a certain level, depending upon the elevation of the outlets and the volume of the discharge, through them, of the heated waters, with the accompanying steam and gases.

Not only has the hydraulic head been controlled by outlets to the surface, but the escape of the solutions from the fissures into the walls and into the country-rock adjacent, especially in mines in limestone, has also acted to some extent in the same way. The slow circulation of the mineral-depositing solutions

through large caves or chambers, or through the interspaces in great masses of brecciated rock, from the extent of surface exposed and the free escape of steam and gases, has caused a reduction of both temperature and initial pressure.

During the long period of ore-deposition, fluctuations caused by any increase or diminution of pressure or of temperature in the ascending waters would naturally occur in the hydrostatic level. It must have been subject to various accidents, such as the opening of new outlets at lower levels, or the choking or closing, by any cause, of outlets long in action. Moreover, the upflow through the fissure would be modified by crustal movements opening or closing its channels, and thus affecting both its volume and its pressure. Many other factors—for instance, the specific gravity of the solutions and the proportion of steam and gases mingled with them—must have had their effect.

The mixture of a liquid with a gas reduces the weight of a given column; and, when this column is under a hydraulic head not thus affected, this reduction of its weight is equivalent to an increase of pressure, in augmenting its flow. Friction produces a loss of effective head, which rapidly increases in contracted or tortuous channels, and must become very great where the solutions spread out and transverse the interspaces of fractured or brecciated rocks.

Since the completion of the primary ore-deposition, oxidation and re-formation of the minerals have tended to move the ore-crest downward in the fissures; but the quartz and other gangue-minerals remain, together with oxidized ores in such quantity that there is usually little difficulty in determining the original crest-level.

In most mining regions erosion has been so great, since the period of mineral-deposition closed, that many hundreds and often thousands of feet of strata have been removed, destroying all record of what occurred in the upper part of the veins. So far as observed by the writer, mineral crests such as have been described above occur only in those districts in the Basin Region where, at the time the ores were deposited, the surface was deeply cut by erosion, and the later climatic conditions have been such as to preserve the old surface with little alteration—a combination of conditions which must be regarded as exceptional.

Now that attention has been drawn to this subject, it is not improbable that like occurrences will be found in other mining regions of the world; and we may certainly look for the discoveries of similar deep-seated ore-crests not formed and determined chiefly, or at all, by the position of surface-outlets, but due to the inadequacy of the initial pressure of the heated waters to force them to the surface—a condition comparable to that of many artesian basins, where flowing wells do not exist, because the hydrostatic level is underground.

The observations of the writer indicate that ore-crests are not confined to veins or lodes of replacement in limestone, but may occur in fissure-veins in quartzite, and in lodes traversing eruptive granitic rocks.

The Reactions of the Ziervogel Process and Their Temperature-Limits.*

BY ROBERT HENRY BRADFORD, B.S., UNIVERSITY OF UTAH, SALT LAKE CITY, UTAH.

(New York and Philadelphia Meeting, February and May, 1902.)

THIS investigation was undertaken at the suggestion of Prof. Henry M. Howe, of the Department of Metallurgy, Columbia University, who, in a letter to the author, dated October 23, 1900, wrote as follows, suggesting the subject of this dissertation:

"The extraction of silver from copper-mattes by either the Ziervogel or the Augustin process depends upon converting the silver into silver sulphate by means of the sulphuric anhydride evolved from the decomposition of ferrous sulphate and cupric sulphate, which are formed during the roasting operation itself from the iron and copper sulphides present.

"It occurred to me, some time prior to the autumn of 1897, that these processes might be made much easier by adding to them, at the proper stage, ferrous or cupric sulphate, or both, in the form of green or blue vitriol. That is, instead of having to rely solely on our ability to generate these sulphates in this very delicate roasting operation, my idea was that we could add a small quantity of already-prepared sulphate at the proper state of roasting, viz., at or before the period when the sulphatizing of the silver occurs.

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* This paper was submitted as a thesis for the degree of Doctor of Philosophy at Columbia University, New York City; and at the same time accepted by the American Institute of Mining Engineers for publication in the *Transactions* of that Society.

"Besides iron and copper sulphates, I have also thought of the addition of alkaline sulphates for the same purpose, especially of sodium sulphate, which has been used for sulphatizing copper in roasting.

"It seems to me that the Ziervogel process, either alone or jointly with the Augustin process, would form a very useful and interesting subject for your thesis, especially if studied with a view to determining the ranges of temperature and other conditions most favorable to the formation, and those which cause the decomposition, of ferrous, cupric and silver sulphates respectively; including in your investigation this idea of facilitating the sulphatization of the silver by the addition of green or blue vitriol or sodium sulphate, or two or all of them.

"In doing this I should like it distinctly understood that the work is to be done purely for the advancement of science, and that, if any useful result is reached by the experiments, it is not to be patented by either of us, but is to be published at once for public benefit."

The author would express the deepest gratitude to Prof. Howe for the constant interest he has taken in the progress of the work, and for the valuable counsel he has given on lines of investigation.

The Ziervogel Process.

The Ziervogel process was invented in 1840* by Hüttenmeister Ziervogel, of the Gottesbelohnungshütte, and was first brought into use in 1844, at Mansfeld, Prussia, by its inventor. Since that time it has been applied more or less continuously at Mansfeld, and at various other places in Europe and in this country, for extracting silver from copper-mattes.

This very simple, though delicate, process depends upon the fact that the silver in copper-mattes is converted into silver sulphate by means of the sulphuric anhydride evolved from the decomposition of iron sulphate and copper sulphate, which are formed during the roasting operation from the iron and copper sulphides present in the mattes. The process consists in roasting the sulphides in excess of air, so that they are oxidized partly to sulphates, which are then heated sufficiently to decompose the sulphates of iron and most of the sulphates of copper, while the silver remains sulphatized, and may be dissolved out with boiling-water and subsequently precipitated on metallic copper. Simple as it appears, this process is extremely difficult to execute, for it requires a very high degree of skill to seize the exact period when the iron and copper sulphates are converted into their insoluble higher oxides and none of the silver sulphate is decomposed.

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* Lamborn, *Metallurgy of Copper*, p. 147.

Object of This Investigation.

This investigation was undertaken with the view (1) to determining the conditions most favorable to the formation and those which cause the decomposition of the sulphates of iron, copper and silver respectively; and (2) to finding out if these processes might not be made much easier by adding at the proper stage ferrous or cupric sulphate or an alkaline sulphate. Instead of having to rely solely on our ability to generate and control the sulphates in this very delicate roasting operation, could we not add a small quantity of some sulphate at the proper stage of the process, and thereby get the desired results?

Steinbeck's Experiments.

Steinbeck,* in 1862, carried out a series of most valuable experiments on the chemistry of the Ziervogel process as then operated at Mansfeld; and his dissertation is to this day considered classic. He attempted to ascertain approximately the temperature at the various stages of the operation, but the lack of suitable means for accurately measuring high temperatures made it impossible for him to get reliable results. To show the limitations under which he worked, I quote from Steinbeck:† "Lacking a pyrometer, with the help of which high temperatures could be determined with certainty, I contented myself in approximately determining the temperature of the heating charge by means of metals with well-known melting-points. These were exposed continuously for 5 to 5½ hours during the roast in the upper hearth in a spoon 2″ x 2″, made of sheet-iron. By means of a cover made of a non-conducting substance, the heat from the gases near the arch of the furnace was kept out. The cover was made of two concave pieces of porcelain placed together, with their concave sides toward each other and with wood-ashes between them, the two parts being held together by wire. The fusion was thus accomplished through the temperature of the roasting mass, as the crucible was continuously moved back and forth in the roasting-material." Table I. gives the metals and their melting-points used by Stein-

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* *Chemisch-Analytische Untersuchungen uber die Veränderungen, welche der Mansfelder Kupferstein bei seiner Röstung behufs Entsilberung durch die Ziervogel'sche Extractionsmethode erleidet,* Dr. G. V. A. Steinbeck. Also, *Zeitschrift für das Berg-, Hütten, und Salinenwesen in dem Preussichen Staate,* vol. xi., No. 2, p. 95.

† *Chemisch-Analytische Untersuchungen,* etc., p. 48.

TABLE I.—*Melting-Points.*

	Tin.	Bismuth.	Lead.	Zinc.	Antimony.
Used by Steinbeck	235° C.	270° C.	334° C.	412° C.	425° C.
Obtained with improved pyrometers*	232° C.	269° C.	327° C.	420° C.	630° C.

beck, and also the melting-points as determined by the use of improved pyrometers.

With some of the metals no grave difference is noticed on comparing the melting-points employed in his experiments with those recently determined; but in the case of antimony the error is seen to be more than two hundred degrees. Having adopted so low a melting-point for antimony, Steinbeck was led to erroneous conclusions as to the temperature in various stages of the roasting operation, as instanced by the following statements: "At the expiration of one hour and fifteen minutes the entire roast was of a dull-red color; yet it was not able to melt antimony (425° C.), while zinc melted readily. Also, at the last stage of the roast in the upper hearth, antimony was not fused; after three hours roasting, and after keeping the pan one-half hour in the roasting mass, antimony was still brittle, and could be broken with the pincers, and no trace of fusion was perceivable. On the other hand, zinc could be readily melted to the last moment the matte remained in the upper hearth. From these results, it follows that the temperature which the roast attains in the upper hearth lies between the melting-point of zinc and antimony, and consequently cannot rise above 425° C."

Undoubtedly the temperature had risen above 600° C. during the roasting in the upper hearth, instead of remaining below 425° C.; for the temperature of "dull red" referred to is given as 550–625° C. by Prof. H. M. Howe,† and 566°–635° C. by White and Taylor.‡ Concerning the higher temperatures in the lower hearth, he says: "After the mass had been in the lower hearth, whose arched ceiling and side-walls glowed with a bright-red heat from the 'Feuerungsperiod' of shortly before, for ten minutes,

* Le Chatelier and Boudouard, *Mesure des Températures élevées*, p. 11. Also, *High Temperature Measurements* (a translation of the above by Burgess), p. 208.

† H. M. Howe, *Eng. and Min. Jour.*, Jan. 20, 1900, p. 75.

‡ *Am. Soc. of Mech. Engineers*, Dec., 1899, or *Eng. and Min. Jour.*, Dec. 23, 1899.

antimony (425° C.) was easily brought to fusion. This temperature was greatly exceeded with the roasting mass, but could not be determined, even approximately, for want of metals or alloys with suitable melting-points, but allow it to be approximately estimated at 500° to 550° C." He found that, when antimony was first melted, dehydrated copper sulphate placed in a closed crucible was not decomposed, but retained its white color. Later, this sulphate was decomposed readily on the side of the hearth next the fire.

Apparatus Employed in the Present Experiments.

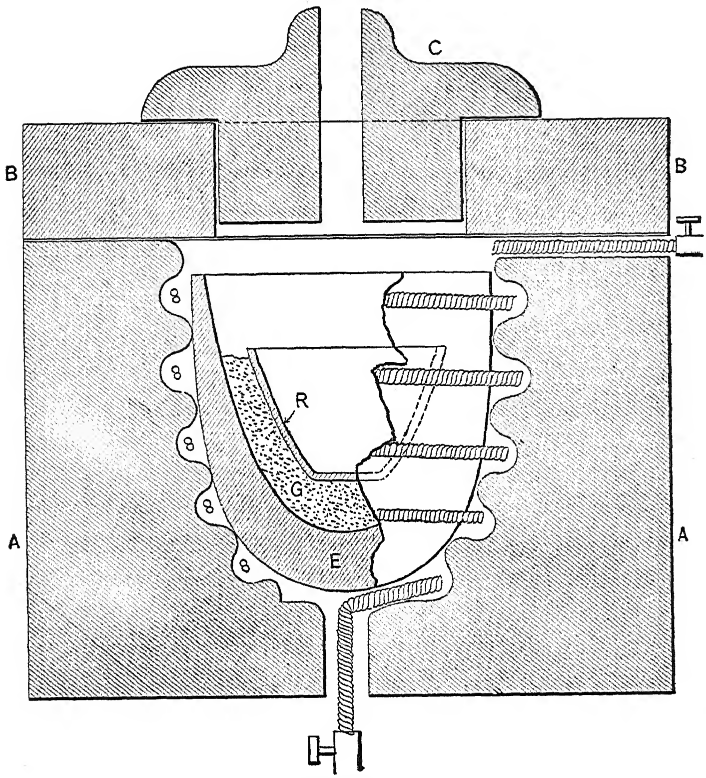
The improvements in pyrometry of the last few years have made it possible to determine accurately the temperature at any stage of the roasting process. The pyrometer employed in this investigation was the Le Chatelier thermo-electric couple, connected up with a d'Arsonval galvanometer mounted on a stone slab arranged on brackets against the wall of the laboratory. The telescope with graduated scale was mounted on the same slab, two meters distant from the galvanometer. The accuracy of this type of pyrometer at high temperatures, and its adaptability for use with small quantities of the substance heated, made it especially applicable to the work in hand.

The Howe electric furnace* used in this investigation was of inestimable value in many of the experiments. It furnished a means of controlling perfectly the temperatures of the heated substances. The material under treatment could be held at a definite temperature for an unlimited time simply by keeping the current through the furnace constant. The rheostats employed in connection with the furnace are described below. Fig. 1 represents the furnace with crucibles prepared for the pyrometer couple and the substance to be heated; and all parts are shown in actual size. The body of the furnace was made up of two hemi-cylindrical blocks of magnesium oxide which, when placed together, formed a cylinder with a cup-shaped depression extending from the upper side. Inside of this depression the cylinder was grooved spirally. The platinum wires (two No. 18 Browne & Sharp gauge, twisted together) were wound into a spiral to fit this groove. Inside this spiral of heating-wire was

* "An Electric-Resistance Magnesia Crucible-Furnace for Laboratory Use," by Dr. H. M. Howe, *Trans.*, xxxi., 568; also *Eng. and Min. Jour.*, Nov. 16, 1901, p. 636.

placed the magnesium oxide crucible. Two shoulders forming an annular ring around the top of the furnace supported the cap or stopper. The pyrometer couple passed through the cap to the crucibles below. The furnace-body and auxiliary parts were of magnesium oxide. Powdered magnesium oxide formed the bed in which the inner platinum or porcelain crucible was placed.

FIG. 1.



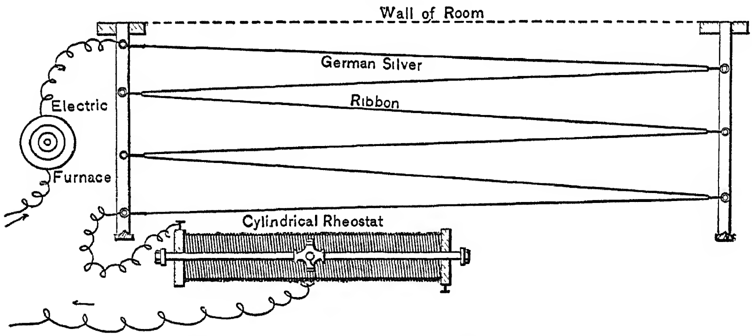
Howe's Electric-Resistance Magnesia Crucible-Furnace.
A, Magnesia furnace-body; B, Magnesia shoulders; C, Magnesia cap or stopper; E, Magnesia crucible; G, Powdered magnesia; R, Interior porcelain crucible.

The resistance of the furnace-wires varied with the temperature, ranging from 0.13 ohm at ordinary temperature of the room to 0.35 ohm at 1200° C. To maintain a temperature of 700° C. required a current of 27 amperes, while for 1000° C. a current of 32 amperes was necessary. The electric furnace was used almost every day, for a period of six months, without any ap-

parent deterioration of the platinum wire, the outer walls, or the inner crucible.

The current was obtained from the direct-current dynamo which supplied the electricity for general use through the buildings of the University. The voltage (115) was much higher than required by the furnace, so additional resistance was introduced. Two rheostats were employed. One was of the cylindrical type designed and used by the Electrical Engineering Department of Columbia University, having a shifting-contact, to furnish steps. This rheostat consisted of 240 coils of "climax" resistance-wire of 3 mm. diameter, wound six coils to the linear inch around a length of 5-in. gas-pipe which had been previously covered with an insulating layer of mica and

FIG. 2.

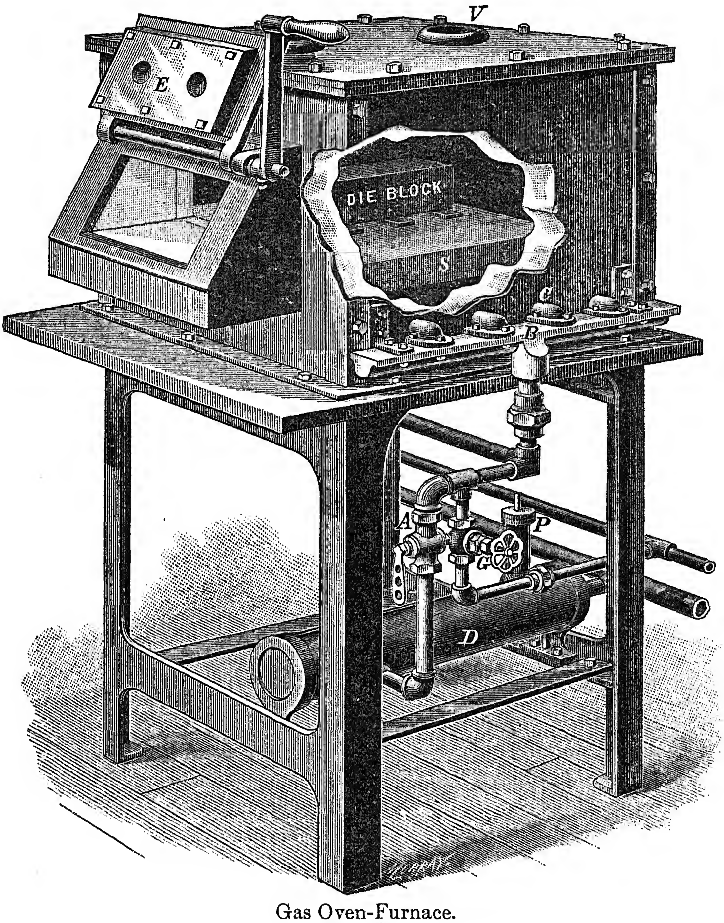


Arrangement of Furnace and Rheostats.

asbestos. The ends of the resistance-wire were connected with binding-posts suitably insulated. An iron rod of $\frac{3}{4}$-in. diameter running longitudinally above the gas-pipe, and attached to the same by a support at each end, carried a sliding-brush in contact with the coils of the rheostat and with a binding-post above. The whole was mounted on four legs, and stood a few inches from the floor. The maximum resistance of this one was 0.8 ohm at the temperature of the room. In connection with the necessary additional constant resistance, this rheostat with sliding contact was used to adjust the temperature between the limits employed. The additional constant resistance was supplied by 72 ft. of German silver ribbon, 0.5″ wide by 0.008″ thick, strung back and forth from cross-pieces, 12 ft. apart, erected along the wall above the furnace. At one

cross-piece each end of the ribbon and each fold was connected by a large copper wire to its binding-post in the cross-piece. Adjustments could easily be made so that two, or four, or six of these lengths were in the circuit. With a current of 40 amperes, the ribbon did not attain a temperature of visible

Fig. 3.



Gas Oven-Furnace.

redness, and did not oxidize to any extent. This simple and inexpensive rheostat was in use almost every day for six months, and was then in good condition. Fig. 2 shows diagrammatically the arrangement of the rheostats and the electric furnace.

The furnace employed to roast the argentiferous matte was

the American Gas Furnace Co.'s No. 4 Oven-Furnace. It is shown in perspective in Fig. 3. The dimensions of the inner hearth were 18″ by 24″.

Methods Employed.

The experiments were begun upon pure sulphates of the metals iron, copper, and silver, respectively. In order to determine at what temperatures these substances begin to decompose at atmospheric pressure by the agency of heat alone, each was taken separately and heated in the electric furnace until decomposition commenced. The thermo-electric couple of the pyrometer was placed in direct contact with the sulphate under treatment. The dissociation of the compound was attended with the absorption of heat. This absorption caused the arrest or retardation in the rate of change of temperature of the substance and couple, and the retardation was readily detected by the slower rate of movement of the galvanometer mirror of the pyrometer. The pyrometer having been previously calibrated, —*i.e.*, the relation of the amount of deflection of the galvanometer to the temperature of the thermo-couple having been ascertained,—the temperature at which the retardation occurred, which was the temperature at which the dissociation began, was thus easily recognized. As part of the sulphate was volatilized on dissociating, it was possible to confirm the results in each case gravimetrically. To confirm in this way, it was only necessary to take a fresh quantity of the sulphate and heat to a temperature just below the point indicated by the retardation, hold the temperature constant for some time, then cool and weigh. The balance, revealing no loss in weight, showed no change to have taken place. This was then heated a second time, this time to a temperature just above retardation, and maintained there for a few minutes. The loss in weight showed definitely that dissociation had taken place. In some cases analyses were made of the residues, to give further evidence of the decomposition.

In order to determine what were the products of the dissociation which began at a certain temperature, the substance was held at a temperature just a few degrees above that at which the reaction was seen to commence, until no further loss in weight was revealed. A constant temperature was maintained

in the furnace during this time, and the crucible and contents weighed at intervals. Many hours were often required for this condition of constant weight. The amount of loss indicated the products of the change, and analysis of the residue confirmed these indications.

It was found desirable to operate with small quantities in catching the exact temperature of retardation with the pyrometer. The couple could then be more conveniently placed in the layer of the sulphate next the crucible, in which layer the action of dissociation commenced. If the position of the point of contact of the couple in the sulphate was any appreciable distance from this first decomposing layer, the temperature of beginning dissociation came high; this effect being due to the influence of the atmosphere of sulphuric anhydride which surrounded the particles of the mass after the layer next the crucible began to decompose.

Experiments with Copper Sulphate.

A quantity of neutral copper sulphate or blue-vitriol crystals was dehydrated by heating to 350° C. and holding at that temperature for some time. The dehydrated salt was white, and remained so when kept in a stoppered bottle. A small amount of this dehydrated sulphate ($CuSO_4$) was placed in a crucible with thin walls and inserted into the electric furnace. The magnesia crucible of the furnace was filled half full of powdered magnesium oxide, and the small porcelain crucible imbedded up to the rim in this powder (see Fig. 1), the idea being to get uniform heating around the sides of the crucible. The contact of the couple of the pyrometer was made as short as possible, in order that the uppermost point of the contact should be imbedded in the small amount of sulphate used. When the couple was in place, the heating-current of the furnace was turned on. Records of time and deflections of galvanometer were taken on blanks provided by the Metallurgical Department, as shown in Table II.

If the conditions of the experiment were carefully arranged, the retardation was decidedly marked, as is shown in the table. If for any cause the couple was not properly placed, the retardation came high, as already explained. As an average of a large number of such tests, the temperature of the first

TABLE II.—*Time-Deflection Readings for $CuSO_4$.*

Series 3. Nos. 1 and 2. Date, March 6, 1902. Object, Dissociation of $CuSO_4$. Reading by R. H. Bradford. Record by R. H. Bradford.

Zero and Cold Junction.	Interval.	Time Rising.	Deflection.	Zero and Cold Junction.	Interval.	Time Rising.	Deflection.
	Sec.	Min. Sec.	Galv. Deg.		Sec.	Min. Sec.	Galv. Deg.
....	....	....	6.0	....	....	....	6.0
....	....	....	.1	....	....	....	.1
....	....	....	.2	....	....	....	.2
....	....	....	.3	....	....	....	.3
....	....	....	.4	....	....	....	.4
28° C.	....	3–23	.5	29° C.	....	6–56	.5
....	22	45	.6	....	17	7–13	.6
....	22	4–07	.7	....	17	30	.7
....	23	30	.8	....	16	46	.8
....	24	54	.9	....	16	8–02	.9
....	28	5–22	7.0	....	18	20	7.0
....	35	57	.1	....	24	44	.1
....	37	6–34	.2	....	24	9–08	.2
....	38	7–12	.3	....	25	33	.3

retardation for dehydrated copper sulphate ($CuSO_4$) was found to be 653° C., and the inference was that this was the temperature at which sulphate of copper ($CuSO_4$) begins to decompose by the application of heat alone.

In order to confirm this result, a weighed quantity (237 milligrammes) of the white dehydrated sulphate was placed in a small porcelain crucible, and the crucible and contents were introduced into the electric furnace and heated slowly to a temperature of 620° C. A constant temperature of 620° C. was maintained for five minutes; then the crucible and contents were removed, cooled and weighed. No loss of weight was observed, and the mass was still white. Again it was heated slowly, and the temperature of 645° C. maintained for a few minutes. No loss of weight, and no change of color to be seen. At the next heating the temperature of 650° to 655° C. was maintained for fifteen minutes, and on cooling a change in color from white to yellow was to be seen near the sides of the crucible, and a loss in weight of 13.1 per cent. of the original sulphate was revealed by the balance. Fumes of sulphuric anhydride were seen to rise out of the annular opening around the couple at the top of the cap of the furnace during the last heating. From these tests dissociation was seen to commence at a temperature between 650° and 655° C.; and the results confirmed those obtained by the retardation of the pyrometer.

To ascertain just how much of the sulphate would be volatilized at the temperature of 653° C., and in this way to determine what the products of the dissociation were, 244 milligrammes of the white dehydrated sulphate were placed in a small platinum crucible and heated to 655° C. to 670° C. for two hours, and until no white salt remained and no further loss could be gotten. The substance had changed color from white to yellow. The loss in weight was 60.5 milligrammes, or 24.8 per cent. of the original weight. The experiment was repeated a number of times, and the average of the percentages of loss due to the dissociation, which began at 653° C., was 25.04 per cent. The yellow salt did not change its color nor increase in weight from absorption of moisture from the atmosphere during four days that the substance was kept under observation. The yellow residues from two of these heatings were analyzed, and gave 53.5 per cent. and 53.12 per cent. copper respectively, with an average of 53.31 per cent. It was practically insoluble in distilled water, changing to a green color after a few minutes' time. From these tests the yellow residue was determined to be the basic copper sulphate of the formula $CuO,CuSO_4$, or

$$SO_2\left\langle\begin{array}{l}O-Cu\\O-Cu\end{array}\right\rangle O,^*$$

in which the percentage of copper is 53.13 per cent. The theoretical loss in weight of two molecules of the neutral sulphate in changing to the basic salt is 25.07, as compared with 25.04 per cent. determined in these experiments. With the electric furnace it was possible to control the temperature so perfectly as to get all the white neutral salt changed to the yellow basic sulphate before any black oxide of copper was produced. This method of obtaining the yellow basic sulphate of copper from the white neutral sulphate had been previously attempted, but without success.† This may be accounted for by the facts that the dissociation proceeds very slowly when the temperature is raised but a few degrees above the point at which the change begins; and that, at a temperature less than 50° higher, the yellow basic salt begins to dissociate with the formation of black oxide of copper and sulphuric anhydride.

* *Roscoe & Schorlemmer*, vol. ii., pt. i., p. 339.

† S. U. Pickering, *Chemical News*, vol. xlvii., p. 182.

The speed of dissociation was much slower when the furnace was kept closed, so that the atmosphere within the crucible was one of sulphuric anhydride, than when the furnace was open at the top, allowing the ingress of air. Even with an open furnace, considerable time was required for the action to become complete. If the material was heated rapidly, it was possible to raise the temperature many degrees above the point at which the decomposition commenced without effecting a complete change. If the gaseous products of the dissociation were rapidly removed, the effect was to greatly hasten the operation. In roasting the argentiferous copper-mattes—especially was this noticed in the muffle-furnace—the speed of dissociation was greatly increased by providing for the rapid removal of the gaseous products.

Treatment of the Yellow Basic Sulphate.

Experiments were carried out with the yellow basic sulphate, obtained by decomposing the white neutral salt, in a manner similar to that already described for the dehydrated blue vitriol. Small quantities were taken in a porcelain crucible and heated in the electric furnace with a uniformly rising temperature. The point of contact of the thermo-couple was imbedded in the yellow powder next the crucible. The time-deflection readings are illustrated in Table III.

TABLE III.—*Time-Deflection Readings for* $CuO, CuSO_4$.

Series 4. Nos. 3 and 4. Date, March 8, 1902. Object, $CuO, CuSO_4$ to CuO. Reading by R. H. B. Record by R. H. B.

Zero and Cold Junction.	Interval.	Time Rising.	Deflection.	Zero and Cold Junction.	Interval.	Time Rising.	Deflection.
	Sec.	Min. Sec.	Galv. Deg.		Sec.	Min. Sec.	Galv. Deg.
29° C.	....	2–55	7.0	27° C.	....	4–26	7.0
....	31	3–26	.1	....	20	46	.1
....	31	57	.2	....	21	5–07	.2
....	32	4–29	.3	....	20	27	.3
....	33	5–02	.4	....	21	48	.4
....	32	34	.5	....	24	6–12	.5
....	33	6–07	.6	....	28	40	.6
....	39	46	.7	....	29	7–09	.7
....	41	7–27	.8	....	31	40	.8
....	40	8–07	.9	....	32	8–12	.9
....	40	47	8.0	....	31	43	8.0
....	40	9–27	.1	....	....	....	.1

Six different trials with the basic sulphate gave the temperatures of retardation as follows: 700° C., 703° C., 701° C., 705° C., 700° C. and 703° C., giving an average of the six as 702° C.

To confirm these results, a weighed quantity of the yellow salt was heated for ten minutes at a temperature of 690°–695° C., then cooled and weighed. No change of weight had occurred, and the color remained the same. This was heated again, this time to 705°, for 10 minutes. On cooling, a layer of black oxide was to be seen next to the crucible, and a loss in weight showed that the temperature of dissociation had been reached. A number of continued heatings at temperatures of 705°–720° C. showed that it was only necessary to allow sufficient time to effect complete change to the black oxide, as was indicated by the loss in weight and change in color, and confirmed by analyses of the residues. Time was found to be an important factor in effecting the complete dissociation; but, as would be expected, the time required was less, the greater the temperature of beginning dissociation was exceeded. With but one gramme of the basic sulphate in the crucible, the mass could be raised to 750° C., and still have the change to oxide incomplete. With 4 or 5 grammes of the substance, the temperature could be brought to 850° C. and higher, without complete change taking place. If the neutral sulphate were heated more or less rapidly, the dissociation into basic salt began at 653° C.; but while this change was taking place, the atmosphere of sulphuric anhydride evolved retarded the change of the basic sulphate to the oxide, so that a temperature above 702° C. could be obtained without the appearance of any black oxide.

From these experiments on blue vitriol ($CuSO_4 + 5Aq$), it is seen that the neutral sulphate commences to change to the basic sulphate at the temperature of 653° C., and that cupric oxide begins to form at a temperature of 702° C. If these temperatures be but slightly exceeded, and if the sulphuric anhydride is not readily removed, the change is slow. A higher temperature and a more open furnace effects a more rapid action.

Experiments with Ferrous Sulphate.

A crystal of chemically pure green vitriol ($FeSO_4 + 7Aq$), weighing 840 milligrammes, was heated in a small porcelain

crucible arranged in the furnace in the same manner as described for copper sulphate. After dehydrating, the mass was pressed down onto the bottom of the crucible, and the junction of the thermo-electric couple was imbedded in the powder. The heating-current of the furnace was turned on, and the temperature rose slowly, though not so uniformly as in the case of the sulphates of copper. As a temperature of 585° C. was reached, a retardation in the rate of heating was indicated, as shown in Table IV.

TABLE IV.—*Time-Deflection Readings for $FeSO_4$.*

Zero and Cold Junction.	Interval.	Time Rising.	Deflection.	Zero and Cold Junction.	Interval.	Time Rising.	Deflection.
	Sec.	Min. Sec.	Galv. Deg.		Sec.	Min. Sec	Galv. Deg.
....	....	....	5.1	....	....	....	5.1
....	....	....	.2	....	....	....	.2
....	....	....	.3	....	....	....	.3
....	....	....	.4	....	....	....	.4
....	....	5–43	.5	....	....	6–40	.5
....	11	54	.6	....	11	51	.6
....	11	6–05	.7	....	12	7–03	.7
....	11	16	.8	....	14	17	.8
....	12	28	.9	....	15	32	.9
....	11	39	6.0	....	15	47	6.0
28° C.	13	52	1	....	15	8–02	.1
....	12	7–04	.2	27° C.	15	17	.2
....	15	19	.3	....	17	34	.3
....	16	35	.4	....	19	53	.4
....	16	51	.5	....	20	9–13	.5
....	17	8–08	.6	....	20	33	.6

The retardation is seen to be slight; yet, from a number of concordant results, the retardation was observed to occur regularly at the same temperature of 590° C.

Attempts to confirm this result by heating weighed quantities of the ferrous salt in an open crucible and noting the temperature at which loss in weight was first observed were not successful, owing to the fact that the ferrous sulphate tends to oxidize when heated in the presence of air. It was found that, after dehydrating, if the substance were heated to successive temperatures above 300° C., and held for half an hour, an increase in weight was observed in every case, until a temperature of about 535° C. was reached. Above this temperature a reduction in weight was revealed. The amount of increase in weight for half an hour at 515° C. was only 1.03 per cent. A

portion heated to 535° for twelve minutes showed absolutely no change in weight, and, when heated to 540° C. for two and a half hours, gave a decrease of 5 per cent. of the original ferrous salt employed. The rate of decrease was slightly greater at 550° C., and at 565° still greater. The tendency of the ferrous salt to become oxidized in air accounts for the increase in weight referred to. The reduction in weight which began below 590° C. was undoubtedly due to the fact that the ferric sulphates formed by the partial oxidation of the ferrous sulphate dissociate at a lower temperature than does the ferrous salt itself.

To overcome the difficulty of oxidation which takes place in an open vessel, a sample of the ferrous sulphate was heated in a glass bulb-tube, three inches long, and drawn out at a point near the substance to an internal diameter of $\frac{1}{8}$ of an inch. The bulb containing the substance was placed in the powder within the magnesia crucible of the furnace, and the other end of the tube extended up through the cap of the furnace. In this tube the oxidation was inappreciable. The weight remained constant, as shown by the balance after each successive heating of 10 to 20 minutes to temperatures between 500° and 585° C. When a temperature of 590° C. was reached, fumes of SO_3 appeared at the mouth of the tube. The tube was kept at 590° C. for 30 minutes, and then cooled and weighed, and a loss of weight showed the dissociation to have commenced. The loss was very slight, but a sublimate of sulphuric anhydride, which rapidly changed to sulphuric acid, was observed near the cooler end of the tube. The dissociation was extremely slow in this tube, as instanced by the fact that when the temperature was held at 625°–635° C. for 2 hours, a loss of weight of only 3 per cent. was effected. This showed the decided effect on the rate of dissociation of a dense atmosphere of the sulphuric anhydride evolved.

Silver Sulphate.

Silver sulphate was prepared by dissolving pure metallic silver in boiling sulphuric acid and evaporating to dryness or until every trace of free acid was removed. A porcelain evaporating dish was used, and care was taken not to allow the gas flame of the Bunsen burner to play over the dish. In the presence of reducing-gases, the sulphate of silver was decomposed

at a very moderate heat, metallic silver being deposited. Three grammes of the silver sulphate thus prepared were placed in a Royal Meissen porcelain crucible and heated in the electric furnace. The junction of the couple of the pyrometer was placed in direct contact with the salt for investigations up to a temperature near 850° C. For higher temperatures the couple was enclosed in a porcelain tube of ⅜-in. internal diameter, 4 in. long, closed at lower end. The temperature rose uniformly until 660° C. was reached, when the substance melted, causing a decided arrest or retardation of the pyrometer. On cooling, the freezing-point of the sulphate was readily indicated in a similar way. The freezing-point came at 655° C.,* a few degrees below the melting-point in every case. No further irregularity in the rate of heating and no disturbance in the liquid sulphate could be observed until a temperature of 1095° C. was attained. Here the liquid filled with bubbles, and quantities of sulphuric anhydride were evolved. If the temperature were held at 1095 C., the evolution of gas proceeded rapidly until all was decomposed, leaving molten metallic silver in the crucible. But if the furnace was allowed to cool a few degrees, the reaction ceased, and the liquid sulphate again became quiescent. The experiment was repeated a number of times, and the rapid evolution of gas commenced in each case at 1095° C.

In the next experiments, to determine if any decomposition occurred when the sulphate was heated to, and maintained at, temperatures below that of this rapid dissociation, 1.195 grammes of the sulphate were heated to 866° C. for five minutes. No metallic silver appeared, and the balance indicated no appreciable loss in weight. On heating to 970° C. for five minutes, the loss in weight amounted to 3.5 milligrammes, or ⅓ of 1 per cent. Again the mass was heated, this time to 1050° C., for five minutes. The loss was 25 milligrammes, or over 2 per cent., and metallic silver appeared in globules around the crucible. A fresh quantity of the salt weighing 2.966 g. was heated for one hour and twenty minutes to a temperature of 900° C. On cooling, particles of metallic silver adhered to the sides of the vessel. The analytical balance showed a loss of weight of 46 milligrammes, or 1.6 per

* Carnelley gives the melting-point of the sulphate of silver as 654 ± 2. *Journal of the Chemical Society,* vol. xxxii. (1878), p. 279.

cent. On heating the same mass to 920° C. for an hour and thirty minutes, a thin layer of metallic silver covered the unchanged sulphate, which layer became somewhat thicker after heating to 945° C. for one hour. The loss in weight had now reached 6 per cent., showing one-fifth of the sulphate to be decomposed.

In order to determine whether the reduction of metallic silver at temperatures as low as 900° C. was not due to the reaction of the sulphate on the porcelain of the crucible, these experiments were repeated in a platinum vessel. The results with the platinum vessel confirmed those with the porcelain crucible, and are given in Table V., along with those with the porcelain crucible.

TABLE V.—*Rate of Dissociation of Ag_2SO_4 at Different Temperatures.*

Quantity of Ag_2SO_4.	Kind of Crucible.	Temp to which Substance was Heated.	Time during which the Temperature Remained Constant.	Loss in Weight.	Percentage Loss.	Remarks.
Grms.		Deg. C.		Grm.	Per Cent.	
1.800	Platinum.	750	10 min.	No loss	....	....
"	"	825	10 "	0.002	0.11	No silver.
"	"	850°–860	15 "	0.004	0.22	"
"	"	850	40 "	0.004	0.22	"
"	"	880°–890	3 hours.	0.180	10.00	Much silver.
1.195	Porcelain.	866	5 min.	trace.	....	....
"	"	970	5 "	0.0035	0.30	....
"	"	1050	5 "	0.025	2.10	....
2.966	"	900	1 hr. 20 min.	0.046	1.60	Globules of silver.
1.302	"	900	40 min.	0.008	0.62	....
0.619	"	880°–920	15 "	0.009	1.45	....
"	"	1020	....	0.0155	2.50	....
0.8515	"	955	30 min.	0.005	0.6	....
"	"	965	30 "	0.009	1.05	....
0.743	"	1010	1 hr. 20 min.	0.053	7.10	Globules of silver.

After maintaining the silver sulphate in the platinum vessel at temperatures of 825° C., 860° C. and 850° C., respectively, for periods of time amounting in all to one hour and five minutes, the total loss in weight was less than 0.6 per cent., and no metallic silver could be found. After fifteen minutes at 900° C. the loss amounted to more than double that which had occurred during the whole hour at the lower temperatures, and metallic silver was to be seen around the vessel. After three hours at 880°–890° C. the loss had reached nearly 12 per cent.,

showing 40 per cent. of the sulphate to be decomposed. The loss in weight by continuous heating could be detected at any temperature above its melting-point (655° C.). Below 860°–870° C. this loss was extremely small, and no metallic silver appeared even after an hour's time, so that the loss seemed to be due to the evaporation of the molten sulphate as such rather than to the dissociation of the salt. At temperatures of 860°–870° C., and above, the loss in weight was much more rapid, and the deposition of metallic silver indicated the decomposition of the silver sulphate. But not until 1095° C. was reached was there any agitation of the liquid due to the formation of bubbles of gas throughout the substance.

In roasting argentiferous copper mattes the silver sulphate formed is associated with the oxides of iron and copper. To determine whether these oxides have any effect on the dissociation of the sulphate of silver, the sulphate was heated with (1) cupric oxide, (2) silica, and (3) ferric oxide. The reduction of metallic silver was found to be much more rapid when either of these oxides was present, as shown in Tables VI., VII. and VIII. In each case the reduction commenced at the same temperature, and this temperature corresponded with that at which the dissociation began when the sulphate was heated alone, viz., 860°–870° C. When heated to 870°–890° C. for three hours with four times its weight of cupric oxide, the sulphate was all reduced; while the sulphate alone, for an equal time, at the same temperature, showed a loss of only 10 per cent., corresponding to a decomposition of but $\frac{1}{3}$ of the sulphate present. When heated with either silica or ferric oxide, the decomposition above 860°–870° C. was fully as rapid as with cupric oxide. (See Tables VII. and VIII.)

TABLE VI.—*Results of Heating Sulphate of Silver and CuO.*

Quantity of Substances.	Kind of Crucible.	Temp. to which Substance was Heated.	Time during which the Temp. Remained Constant.	Loss in Weight.	Percentage Loss.	Remarks.
Gramme.		Deg. C.		Grm.		
$\begin{cases} Ag_2SO_4 \ 0.3235 \\ CuO \ 0.8155 \end{cases}$	Porcelain.	820	5 min.	0.0015	....	....
"	"	875	5 "	0.009	....	....
"	"	875	15 "	0.018	....	....
"	"	870	55 "	0.0525	....	....
"	"	880	1 hr. 20 m.	0.019	All Ag_2SO_4	Decomposed.

TABLE VII.—*Sulphate of Silver and Silica.*

Quantity of Substances.	Kind of Crucible.	Temp. to which Substance was Heated.	Time during which the Temp. Remained Constant.	Loss in Weight.	Remarks.
Gramme.		Deg. C.		Grm.	
{ Ag_2SO_4 0.471 / SiO_2 0.3475	Porcelain.	770	30 min.	None.	....
"	"	815	5 "	None.	....
"	"	840	5 "	None.	....
"	"	860	5 "	None.	....
"	"	870	2 "	0.011	Much metallic silver.
"	"	870–900	30 "	0.051	Much metallic silver.

TABLE VIII.—*Sulphate of Silver and Ferric Oxide.*

Quantity of Substances.	Kind of Crucible.	Temp. to which Substance was Heated.	Time during which the Temp. Remained Constant.	Loss in Weight.	Remarks.
Gramme.		Deg. C.		Grm.	
{ Ag_2SO_4 0.535 / Fe_2O_3 0.630	Porcelain.	850	10 min.	0.001	No silver.
"	"	870–890	10 min.	0.0053	Some metallic silver.
"	"	"	1 hr. 30 m.	0.080	Much silver.

Cuprous Oxide.

If cuprous oxide (Cu_2O) is added to a solution of silver sulphate in water, metallic silver is reduced and appears as spangles according to the following equation: $Ag_2SO_4 + Cu_2O = CuO + CuSO_4 + 2Ag$* (called the spangle reaction). Since silver sulphate is in the molten condition above 655° C., it was thought that the presence of cuprous oxide in the roast might cause a reduction of silver from the molten sulphate. It was impossible to ascertain by the loss-of-weight method just when the sulphate of silver began to decompose on being heated with cuprous oxide, as some of the lower oxide of copper became oxidized to the higher oxide by the oxygen of the atmosphere, with a corresponding increase in weight. This increase could have more than offset the loss due to the reduction of the sulphate of silver. It was therefore necessary to adopt some other method of ascertaining just when this change commenced, providing it did occur.

* Balling, *Metallurgische Chemie*, p. 58. Plattner, *Grillage*.

After each heating, some of the mixture was removed from the crucible and examined with a microscope for particles of metallic silver. No indication of the metal could be found until the temperature rose to the point at which the change began with the sulphate alone, or with the sulphate in the presence of the other oxides, viz., 860°–870° C. Tabulated results of these heatings are given in Table IX.

TABLE IX.—*Sulphate of Silver with Cuprous Oxide.*

Quantity of Substances.	Kind of Crucible.	Temp. to which Substance was Heated.	Time during which the Temp. Remained Constant.	Increase in Weight.	Remarks.
Gramme.		Deg. C.		Grm.	
{ Ag_2SO_4 0.215 { Cu_2O 1.028	Porcelain.	670	5 min.	0.088	....
"	"	805	5 "	0.008	....
"	"	825	5 "	0.007	....
"	"	861	5 "	0.003	No metallic silver.
"	"	900	30 "	Loss 0.004	Metallic silver appears
"	"	900	10 "	0.015	Much metallic silver.

Owing to the reduction above described, there must be no cuprous oxide in the roasted matte when ready for leaching. During the earlier stages of the roast, while considerable sulphur in the sulphide condition is present, more or less of the cupric oxide is reduced to the cuprous state through the reducing action of these sulphides. This lower oxide must be reoxidized by continuing the roasting operation with excess of air before leaching is begun. It is also known that cupric oxide is reduced to cuprous oxide by heat alone* at a high temperature. To determine at what temperature this reduction to cuprous oxide occurs, a series of experiments were carried out.

A quantity of crystallized copper sulphate was dehydrated, and then heated to a temperature of 840° C. until the whole was decomposed to black oxide, as indicated by its color and by the loss in weight. A weighed portion of this cupric oxide was heated in a porcelain crucible in the electric furnace. The couple of the pyrometer was placed in direct contact with the

* Favre and Maumené, *Comptes Rendus*, 18, 658. Debray and Joannis, *Comptes Rendus*, 99, 583.

black powder. The heating current of 36 amperes was turned on, and the temperature rose rapidly. Readings of time and deflections of the galvanometer were recorded after the temperature rose above 840° C. The mirror of the galvanometer moved regularly up to 1050° C., where a slight retardation was detected. The change in rate of movement of the galvanometer mirror was very slight, but repeated experiments seemed to indicate some change at this temperature. To determine whether this was the temperature at which dissociation of cupric oxide into cuprous oxide and oxygen commenced, the gravimetric method was employed. Three hundred and thirty-eight milligrammes of cupric oxide were heated to 900° C., then cooled and weighed. The analytical balance revealed no loss in weight. Again to 945° C., 1000° C. and 1045° C. respectively, with the same results. The heated oxide was cooled slowly in the furnace in some instances, and in others rapidly in open air. No loss in weight could be obtained up to 1045° C. After heating to a temperature slightly above 1050° C., the highest point being 1065° C., a loss in weight of 1½ per cent. indicated a partial change to have taken place. The loss was increased to 4.5 per cent. by heating again to the same temperature for ten minutes. The Royal Meissen crucible gave most uniform results. With some other makes of crucible the oxide of copper seemed to react with the crucible at temperatures below 1050° C., occasioning at times a loss in weight. The experiments were repeated a number of times with a platinum dish in place of the porcelain one. Some results with the platinum dish are as follows: 611 milligrammes of cupric oxide were heated to 1000° C. for fifty minutes, and cooled rapidly out of the furnace. No change in color nor loss in weight. Again to 1035°–1045° C. for three hours, with like results. No change could be effected up to 1045° C. After heating again to 1050°–1060° C., a loss in weight indicated a partial reduction to the lower oxide.

Fusion of the Reduced Oxide.—The reduction was found to proceed slowly at temperatures but slightly above that at which it began. If the temperature were raised much above 1050° C. not only a reduction but fusion occurred. When the substance was heated rapidly, so that time was not given for re-

duction to become complete, a temperature as high as 1150° C. was obtained without fusion. If time were allowed for complete reduction to take place but slightly above 1050° C., the reduced mass fused at a temperature of 1065° C. This fused oxide solidified at a temperature near 1050°, the temperature at which reduction begins. This melting-point and freezing-point of the reduced oxide were found to remain constant, as revealed by the retardation of the pyrometer; but if time were not given for complete reduction to be effected before fusion occurred, a mixture of the cupric and cuprous oxides, with a higher melting-point, would result.

In every case, after this reduction to the lower oxide, the upper portion of the mass was again oxidized to cupric oxide when cooled in air. From this action the question was suggested: Did the reduction begin at a lower temperature than that indicated by the above experiments, and escape detection by the balance because of reoxidation? Fresh portions of the higher oxide were heated to and held at temperatures ranging from 800° C. to 1100° C., and cooled in an atmosphere of nitrogen.

Methods of Preparing and Using Nitrogen.

The nitrogen gas was prepared by passing air through heated ammonia-water and then over heated shot-copper contained in a glass combustion-tube. This tube was two feet long, and was kept red-hot by an ordinary combustion-furnace. From the tube the gas was conducted through two wash-bottles, one containing sulphuric acid and the other an alkaline solution of pyrogallic acid, and then into a gas-tank. After the copper in the tube was heated to redness, the apparatus was connected up and the current of air and ammonia passed through. The necessary suction was produced to draw the gases through the apparatus by operating a siphon from the inner side tube of the gas-tank. Oxidation began at the inlet end of the tube, and a portion of the copper-shot was coated with red oxide. The oxide of copper reacted on the ammonia, extracting its hydrogen and setting nitrogen free, the cuprous oxide being reduced by the reaction to metallic copper.

$$2NH_3 + 3Cu_2O = N_2 + 3H_2O + 3Cu_2.$$

This reducing action of the ammonia gave fresh surfaces of metallic copper for extracting the oxygen from the current of air. The excess of ammonia and the water formed in the process were collected by the sulphuric acid in the first wash-bottle. The alkaline solution of pyrogallic acid was provided to take up any oxygen which the metallic copper did not extract. The nitrogen collected came partly from the air and partly from the ammonia.

It was found to be necessary to operate slowly, in order that the reaction in the tube should be complete. As a further precaution, the tank of nitrogen collected was again passed through the tube of heated copper and through fresh solutions, to make sure that every trace of oxygen was removed. No trace of either oxygen or ammonia could be detected in the nitrogen from this second tank.

All the openings and joints of the electric furnace were luted with fire-clay except the annular space around the porcelain tube which carried the couple through the cap, after the crucible with the cupric oxide had been placed in position. The oxide was heated to the desired temperature and held there for some minutes; then the porcelain tube and couple were removed, and a similar tube, open at both ends, was placed in the opening through the cap, the lower end of the tube coming next to the heated oxide. This tube was connected with the gas-tank (nitrogen had been passed through the rubber tubing and porcelain tube to remove the air from them) and the nitrogen was turned on. The heating-current was cut off and the furnace and contents allowed to cool. In this way the cooling oxide was continuously surrounded by an atmosphere of nitrogen.

A brief description of these tests, and the results of the same, are here given: 1.735 grammes of cupric oxide were heated to 950° C. for fifteen minutes, then cooled in an atmosphere of nitrogen as above described. The analytical balance revealed no loss in weight, and the color remained black. No change had occurred at this temperature. Another sample was heated to 1035° C. for ten minutes, and cooled in nitrogen. No change in color and no loss in weight could be detected. On heating the same again to 1065° for ten minutes, and cooling in a similar manner, the color had changed to reddish brown,

and the balance revealed a loss in weight of 8 per cent. After heating for twenty minutes to the same temperature, and cooling in nitrogen again, the loss was found to be increased to 9 per cent., out of a possible 10 per cent., which is the calculated loss for a complete change of cupric into cuprous oxide.*

These results confirmed those without the nitrogen, except that the reductions as shown by the balance for temperatures above 1050° C. were greater for corresponding lengths of time. This was due to the absence of reoxidation in the atmosphere of nitrogen. No reduction to the lower oxide was found for temperatures below 1050° C.

The dissociation of the higher oxide of copper into the lower oxide was found by the above-described experiments to occur at 1050° C., a temperature nearly 50 degrees below that at which the rapid reduction of silver sulphate begins, but nearly 200 degrees above that temperature at which silver sulphate commences to decompose slowly when alone, and more rapidly in the presence of the oxides of copper and iron. This reduction of cupric to cuprous oxide by heat alone is, therefore, not of importance in the Ziervogel process, as it is effected only at a temperature two hundred degrees above that at which the roasting mass can safely be heated, because of other reactions.

Magnetic Oxide of Iron.

Magnetic oxide of iron reduces metallic silver from a solution of silver sulphate† according to the following equation: $4Fe_3O_4 + Ag_2SO_4 = 6Fe_2O_3 + SO_2 + 2Ag$. This reaction is much less rapid than that of the reduction of the metal by cuprous oxide. The reaction is so slow that the presence of small quantities of the magnetic oxide in the roasted matte is not fatal to the leaching process, as is shown by the following experiment: 50 milligrammes of silver sulphate were placed in each of two small beakers and dissolved in hot water. To one was added one gramme of finely powdered magnetic oxide of iron. The oxide employed was magnetite from Port Henry, N. Y. The solution, with the powdered magnetite, was heated for ten minutes near the boiling-point of water. This solution was

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* $2CuO = Cu_2O + O$

$(160) = (144) \quad (16).$

† Plattner, *Grillage*, p. 141, par. 3. Balling, *Metallurgische Chemie*, p. 57.

then filtered and washed, and both the solutions of sulphate were titrated with ammonium-sulpho-cyanate. The results of the titration showed 7.6 c.c. for the solution which had been treated with the magnetic oxide, and 7.8 c.c. for the other solution. The loss due to the magnetic oxide was only 2.56 per cent.

When ferric oxide (Fe_2O_3) is subjected to a high temperature it is reduced to magnetic oxide (Fe_3O_4). To determine at what temperature this reduction occurred, providing it came within the limits of temperature allowable in the Ziervogel process, a series of experiments were carried out in a manner similar to those described for cupric oxide. It was found that no reduction to magnetic oxide was effected until a temperature above 1100° C. was reached. The exact temperature at which dissociation commenced was not definitely determined. The tests, however, showed that the change of ferric to magnetic oxide by heat alone, coming at so high a temperature, was not of importance in the roasting process.

Oxidation of the Sulphides.

The temperature at which the sulphide begins to oxidize in a current of air was not determined for each individual sulphide. It was found on roasting copper mattes in the oven-furnace that, owing to the large amount of sulphur in them, as soon as rapid oxidation commenced, the temperature rose rapidly to 450° to 500° C. Since an excess of air is desirable to get the oxidation to the sulphate* instead of the formation of SO_2 and the oxides of copper, this rapid rise in temperature cannot be readily prevented. The principal part of the oxidations occurs above 450° C.† The exact temperature at which oxidation commences is of little consequence in the process.

ROASTING OF ARGENTIFEROUS COPPER MATTES.

The operation of roasting the argentiferous mattes was carried on in the gas oven-furnace described and illustrated in Fig. 3. Temperatures up to 900° C. could be readily obtained in the furnace, and by regulating the gas and blast, the heat

* "The Metallurgy of Argentiferous Copper Compounds." H. M. Howe. *Production of Gold and Silver in the U. S.*, Burchard, Washington, 1883, p. 757.

† Steinbeck, *Chem.-Analy. Untersuchungen*, p. 49.

was easily kept under control. Cast-iron trays were employed to receive the matte, and these were placed directly upon the fire-brick hearth. The trays were 20 in. long and 5 in. wide by $\frac{3}{4}$-in. deep, inside dimensions; and the sides and bottom were of uniform thickness of $\frac{3}{8}$-in. Rakes and rabbles of such size as could be worked through the two port-holes in the furnace-door were used to stir the roasting charge. An iron spoon attached to the end of a $\frac{3}{8}''$ rod, and small enough to be inserted into the port-holes, served for taking samples at the various stages of the roast.

The platinum and platinum-rhodium wires of the pyrometer were strung through a doubly-perforated fire-clay tube, $\frac{3}{8}$-in. external diameter. At the end of this long tube, next the junction of the wires, was arranged a short length of doubly-perforated tube of somewhat smaller diameter. By means of this short length, the junction of the couple could be readily raised and lowered, in the material whose temperature was sought, without disturbing the longer tube. When the furnace-door was open, the tubes were passed into the furnace through the open door. If it was necessary to close the door, the tubes were run in through one of the port-holes. The water-bottle containing the cold junctions of the pyrometer was placed on a stand near the furnace-door. The thermo-electric couple was kept within the furnace during the entire time the matte was roasting.

A number of mattes with varying amounts of iron, copper, and silver, were treated, and the samples taken at the different stages of the process analyzed. The matte with which most of the experimental work was done had the composition given in Table X. It was obtained from the Orford Copper Works at Bergen Point, N. J., and its silver content enriched to 100 oz. per ton.

Table X.—*Composition of the Argentiferous Matte.*

	Per cent.
Copper,	50.80
Iron,	22.64
Sulphur,	25.80
Silver,	0.31 (100 oz. to ton)
Lead,	trace.
Gold,	trace.
Arsenic,	trace.
Antimony,	trace.

This was ground fine enough to pass through a 60-mesh screen, and 1½ pounds of the finely-ground material placed in the cast-iron tray, and the tray introduced into the oven-furnace. The furnace was lighted, and the gas and blast so regulated as to cause the temperature to rise slowly. After the expiration of one hour, the temperature had reached 325° C. At this stage the sulphur of the matte began to burn off, and owing to the heat of this combustion the temperature rose rapidly. In fifteen minutes the degree of heat of the charge ranged from 470° C. underneath to 535° at the surface where the oxygen of the air supported the combustion of the sulphur. Continuous stirring was required at this stage to prevent fritting or caking of the particles of the upper layer of the charge. As the matte was stirred, the temperature rose slowly, and at the end of the second hour the material was uniformly heated throughout to 590° C. Until now, the upper portions had been hotter than those below. By this time the major part of the sulphur had been oxidized, and the heat from this source began to decline, so that from this time on the temperature of the upper layer was less than that underneath. At the end of another half-hour the temperature had fallen considerably, and was brought up again only by turning on more gas and blast. The door of the furnace was closed a little later. The highest temperature attained during the four hours the matte was roasting was 750°, and this was attained only at the bottom layer of the matte next the pan, just before the gas was turned off.

The operation was stopped at this stage while the matte had the composition shown in sample No. 7 of Table XI., and continued next day. About ¼ of the partially roasted matte was taken in a roasting-dish of Denver fire-clay and heated in a gas muffle-furnace. The furnace was heated to 720° C., and the dish and contents introduced. The mouth of the muffle was closed by a fire-clay door. In half an hour the temperature had risen to 750° C., and considerable sulphate still remained, as shown by sample No. 9. On removing the door and adjusting the flame so that the muffle did not cool down, a draught was established in the muffle, and heavy fumes of sulphuric anhydride appeared at the top of the flue, indicating a rapid dissociation of the copper sulphate in the furnace. At

the end of 45 minutes every trace of neutral sulphate of copper had disappeared. (See sample No. 10.) There was seen to be a great increase in the rate of dissociation at any temperature with a strong draught through the muffle, over that with closed muffle. This corresponds to the phenomenon observed in connection with the dissociation experiments in the electric furnace. After all the sulphates of copper had been decomposed, the charge was heated to 850°, to determine whether any material loss in silver sulphate occurred below the temperature to which it was found to be safe to heat the pure sulphate of silver in the experiments with the electric furnace.

Samples were taken at intervals of 15 to 30 minutes, and these were put into convenient receptacles, labeled, and set aside for analysis.

Methods of Analysis.

Soluble Sulphates of Iron and Copper.

Each sample was analyzed for (1) sulphates of iron and copper which were soluble in water, (2) insoluble or basic sulphates, (3) silver sulphate, and (4) total copper. Total silver was determined in a few cases. To ascertain the amount of iron and copper sulphates soluble in boiling water, two grammes of the sample were weighed out on the analytical balance and added to 150 c.c. distilled water in a No. 3 lipped beaker. The contents of the beaker were heated on an iron plate to boiling and allowed to remain at that temperature for a few minutes. The solution was filtered into a No. 4 beaker and the residue washed by decantation several times with boiling water, which water served for washing the filter. To the clear solution was added a piece of sheet aluminum, $2'' \times 2'' \times \frac{1}{16}''$, and a few drops of sulphuric acid. The solution was boiled again on the hot plate until all the copper was precipitated and the ferric iron reduced to the ferrous condition. The color-test with ammonium-sulpho-cyanate served to indicate when no ferric salt remained. The solution was decanted through a filter and the precipitated copper washed thoroughly by decantation with hot water, the wash-water being passed through the filter to prevent the loss of any particles of copper poured off. The filtrate was titrated for iron with a standardized solution of potassium permanganate.

The copper in the beaker and on the aluminum plate was dissolved in dilute nitric acid. A few drops of the dilute acid were poured onto the particles of copper on the filter and allowed to pass into the vessel containing the dissolved copper, and the filter was thoroughly washed with distilled water. Ammonia was added in excess, and the blue solution titrated with a standardized potassium cyanide solution. The results of these analyses, given in percentage of the two grammes employed, are shown in columns 4 and 5 in Table XI.

TABLE XI.—*Direct Results of Analysis of Samples.*

No. of Sample.	Time.	Temperature.	Cu as $CuSO_4$.	Fe as $FeSO_4$.	Basic Sulphates.	Silver.
		Deg. C.	Per cent.	Per cent.	Per cent. SO_4.	Oz. per T. = Per cent. of Total Silver.
1	After 75 min.	500–520	4.498	0.374	None.	....
2	" 90 "	550–560	7.656	0.580	1.066	....
3	" 105 "	565–570	8.900	0.610	2.542	....
4	" 120 "	585–595	10.144	0.410	4.305	trace.
5	" 140 "	625–640	11.293	0.403	7.298	20.
6	" 190 "	655–675	11.627	0.255	8.534	40.3
7	" 235 "	720–750	9.057	trace.	11.603	55.1
8	" 245 "	740–750	5.574	None.	8.364	70.
9	" 265 "	750–760	4.115	....	6.068	80.
10	" 310 "	770–780	None.	....	1.213	90.2
11	" 320 "	750–760	....	....	None.	92.8
12	" 340 "	850	....	....	None.	90.4

The residues from all the samples except the last two, after treatment with boiling water, were of a decided green tinge, owing to the presence of particles of hydrated basic sulphate of copper,* which is of a green color. Portions of the residues were heated in a porcelain crucible in the electric furnace, and after dehydration the basic salts were found to commence to decompose by heat alone at 700° C. This temperature corresponds with that at which the basic sulphate $CuO,CuSO_4$ decomposes.

To determine the amount of basic sulphates present, the method used by Steinbeck† was employed. To the residue from the two grammes taken for the previous analyses was added three times its weight of sodium bicarbonate ($NaHCO_3$)

* *Watts's Dictionary of Chemistry*, Muir & Morley (1894). Also Roscoe & Sch., vol. ii., pt. i, p. 339. † *Chemische-Analytische Untersuchungen*, etc.

and enough water to dissolve most of the soda. This was allowed to stand for twenty-four hours with occasional shaking. The solution was filtered and the residue washed by decantation and finally on the filter, to remove every trace of dissolved sulphate. This solution was acidified with hydrochloric acid and the carbon dioxide removed by boiling. Barium chloride was added in slight excess, and the whole was boiled a few minutes and set aside for twelve to twenty hours. The barium sulphate was determined gravimetrically, and from this the percentage of SO_4 from the basic sulphate in the sample calculated. Table XI. gives, in percentage of the two grammes of sample originally taken, the SO_4 obtained by this method. The method is similar to the one given by Fresenius for the determination of lead sulphate. It was adapted by Steinbeck to ascertaining basic sulphates in samples from roasting matte. By careful tests he found that the sodium bicarbonate reacted with all the sulphate present, and had no effect on the sulphides.

Analysis for Silver Sulphate.

For silver sulphate determinations, 0.2 assay ton from each sample was taken and treated with hot water in a similar manner to that employed for the other soluble sulphates. If the copper in the solution amounted to more than 1 to 2 per cent. of the quantity of matte taken, the following method was employed:* To the solution of sulphates was added sodium chloride of about "normal" strength, to precipitate the silver as chloride. Lead acetate and sulphuric acid were added to form a heavy precipitate to carry down the silver chloride. The whole was allowed to stand for six to twelve hours, when the clear liquid was decanted through a filter, and finally the precipitate was removed to the same filter. The precipitate was scorified and cupelled for silver.

If the amount of copper present was less than 1 per cent., the silver in the hot-water solution was determined by titration with standardized ammonium-sulpho-cyanate solution according to "Volhard's method."†

The silver insoluble in hot water was ascertained by treating

* *Manual of Practical Assaying*, Furman, pp. 250–251.

† Liebig's *Ann d. Chem.*, cxc., 1. Sutton, *Volumetric Analysis*, 8th ed., p. 155.

the residue from the solution containing the silver sulphate with strong nitric acid and allowing the solution to stand on the hot plate until the red fumes were driven off. The silver was determined by the combination method given by Furman.* The silver obtained from the residue was added to that from the hot-water solution, to give the total silver in any sample. In Table XI. the silver-content is given in ounces per ton, and since the original matte contained 100 oz. to the ton the figures in column headed "Silver" represent also the percentage of total silver.

Reducing Factors.

The data in Table XI. are not in a condition for direct comparison of the quantities of the sulphates at the various steps in the process. During the roasting operation much oxygen of the air was taken up in the formation of sulphates without a corresponding loss in sulphur. The weight of the charge increased as the sulphates continued to rise in amount, and decreased as these compounds were decomposed. The volume also increased and diminished, as was readily seen within the tray in the furnace. In analyzing the samples taken at successive stages in the process, the same weight of each sample was taken. Because of the rapidly changing weight of the roasting-charge, the amount of copper-, or iron-, or silver-sulphate in these equal weights of samples did not represent the relative amounts of these compounds in the charge at these stages in the process. To enable one to compare the analytical data in Table XI., it was necessary to ascertain quantitatively the change in weight of the roasting-charge.

The total amount of copper in the charge did not change during the operation. The amount determined in equal weights of the respective samples varied through considerable limits. From these varying percentages of copper present in the different samples the change in weight of the charge was ascertained. For a decrease in the percentage of copper an increase in the weight of the charge must have taken place, and for an increase in copper-content of a sample a diminution in the weight of the charge. In other words, the relative weights of the charge

* *Manual of Practical Assaying.*

at different stages are in inverse ratio to the copper-content of equal weights of samples taken at these stages. Table XII. gives the percentage of copper present in each sample taken. Sample 7 shows the lowest percentage of copper. At the time this sample was taken, the weight of the charge was a maximum. Reference to Table XI. shows the maximum total sulphates in sample 7.

Putting the weight of the original matte, before roasting commenced, as unity, we obtain the weight at any step in the operation, as follows:

1 : X : : 39.00 (per cent. Cu in sample 7) : 50.8 (per cent. Cu in original matte).

X = 1.303, which is the ratio of the weight of the charge at the time sample 7 was taken to the weight before roasting commenced. Table XII. gives such a ratio or "reducing factor" for each sample.

TABLE XII.—*Total Copper and Reducing Factor.*

No. of Sample.	Total Copper.	Inverse Ratio or Reducing Factor.
	Per cent.	
Original Matte.	50.80	1.00
1	47.04	1.08
2	44.17	1.15
3	43.42	1.17
4	42.70	1.19
5	41.30	1.23
6	40.64	1.25
7	39.00	1.30
8	44.58	1.14
9	46.19	1.10
10	50.78	1.00
11	50.28	0.99
12	50.29	0.99

By the aid of these "reducing factors" the data of Table XI. may be brought into a condition for direct comparison. By multiplying the percentages of the different sulphates in each sample, as obtained by analysis, by the reducing factor for that sample, one obtains percentages which represent the relative amounts of these sulphates in the entire charge at the time the sample was taken. A table of corrected results may thus be obtained.

Total Copper.

One gramme of each sample was treated with 7 c.c. nitric acid and 5 c.c. sulphuric acid in a flat-bottomed flask of 400 c.c. capacity. This was heated until the nitric acid was expelled and the sulphuric acid was boiling freely, then cooled and diluted with 50 c.c. distilled water. Ammonia was added in excess, and the solution transferred to a 500 c.c. flask, and further diluted to exactly 500 c.c. The flask and contents were allowed to stand until the precipitate of hydroxide of iron had subsided. The time required was from two to five minutes. By means of a pipette, an aliquot part of the blue solution, free from the brown precipitate, was taken out and titrated for copper with standardized potassium cyanide. This method was much shorter than the one ordinarily employed, wherein the copper is removed from the solution containing the iron and copper salts by means of metallic zinc or aluminum. The results from the two methods were found to check very closely. Comparative results on the hot-water solution of some of the samples are given below:

Table XIII.—*Soluble Copper Sulphate.*

Sample, ...	No. 6.	No. 7.	No. 8.	No. 10.
	Per ct.	Per ct.	Per ct.	Per ct.
Aliquot part method, ...	11.7	11.9	9.9	6.7
Aluminum precipitation, ...	11.8	11.9	10.1	6.7

Discussion of Results of Analyses.

Sulphate of Iron.

Table XIV. gives the corrected results of analyses of twelve samples, taken at as many different stages of the process. At a temperature of about 350° C. the sulphur of the sulphides began to burn off, and the temperature rose rapidly until it reached a point near that at which the sulphate of iron is decomposed. The tendency to the formation of this sulphate would not be strong at a point so near the dissociation temperature. The small amount of the sulphate of iron shown in the table may be explained by this fact. The maximum amount of sulphate of iron present would not be sufficient to assist very materially in forming copper sulphate by the evolution of its sulphuric anhydride during dissociation, though it is stated in all the text-books that consider the Ziervogel process, that the copper

TABLE XIV.—*Corrected Results of Analyses of Samples.*

No. of Sample.	Time.	Temperature.	Cu as $CuSO_4$.	Fe as $FeSO_4$.	Basic Sulphates.	Silver.
		Deg. C.	Per cent.		Per cent. SO_4	Oz. per T. Per cent. of Total Silver.
1	After 75 min.	500–520	4.858	0.404	None.	
2	" 90 "	550–560	8.803	0.67	1.226	
3	" 105 "	565–570	10.413	0.71	2.974	....
4	" 120 "	585–595	12.071	0.49	5.123	trace.
5	" 140 "	625–640	13.890	0.49	8.976	25.
6	" 190 "	655–675	14.534	0.32	10.668	50.4
7	" 235 "	720–750	11.774	None	15.084	71.6
8	" 245 "	740–750	6.354	....	9.535	79.8
9	" 265 "	750–760	4.526	....	6.675	88.00
10	" 310 "	770–780	None.	....	1.213	90.20
11	" 320 "	750–760	None.	....	None.	91.87
12	" 340 "	850	None.	....	....	89.50

sulphate is formed through the action of the sulphuric anhydride evolved from the decomposing sulphate of iron. To further ascertain if the iron sulphate played any particular *rôle* in the formation of copper sulphate, a matte containing no iron was prepared and roasted in the manner described above. The rapid accumulation of copper sulphate at temperatures corresponding to those at which this compound appeared in the iron-copper matte showed that the iron sulphate was not essential to the operation of sulphatizing the copper compounds. The rise in the sulphate of copper is a gradual one, and is not dependent on the action of the gaseous products of the dissociation of the sulphate of iron.

The maximum amount of soluble iron sulphate was obtained in sample 3, taken at a temperature of 570°, immediately below that at which ferrous sulphate begins to decompose (viz., 590° C.). This iron sulphate decreased from this time until, at a temperature of 700° C., only a trace remained.

Soluble Sulphate of Copper.

The soluble sulphate of copper reached its maximum at a temperature—measured with the contact of the couple below the upper layer—slightly above that at which its dissociation begins. The surface of the roast at this stage (sample 6) was cooler than the layers underneath the surface; and, while the dissociation had begun below the surface, because of its high temperature, the upper layer, where the sulphate really formed, had not reached the decomposing point, and was supplying the

material that was dissociating underneath. At temperatures near 655° C.—that at which the neutral sulphate begins to decompose—the change in amount of neutral sulphate was not rapid.

After sample 6 was taken the operation was carried on with the furnace-door closed, in order to keep the temperature as uniform as possible, and the gaseous products of dissociation were not readily removed. The result was that the dissociation was slow, though it was continuous, and at a temperature of 750° to 760° (sample 9) about 4 per cent. of the soluble sulphate remained. Fifteen minutes after sample 9 was taken, when the door of the muffle-furnace was opened and a strong draught established, the rate of dissociation was greatly increased. Inside of thirty minutes after the door was opened no soluble copper sulphate remained, as shown by sample 10.

Basic Copper Sulphate.

The basic copper sulphate results not alone from the decomposition of the neutral sulphate, but also from the action of the sulphides and sulphur dioxide on the sulphatizing roast.* It appeared as a trace in sample 2, and increased in amount from that time until it reached a maximum in sample 7. The temperature at the time sample 7 was taken was somewhat above that at which the basic salt ($CuO,CuSO_4$) begins to dissociate. The fact that the surface was cooler than the temperature indicated by the pyrometer may account for this apparent discrepancy; but, as has been shown on page 63, if the neutral sulphate present is decomposing with the evolution of sulphuric anhydride, the dissociation of the basic salt may not begin until a temperature a few degrees above 700° C. is reached. The results in the oven- and muffle-furnaces with the roasting matte confirm those obtained in the electric furnace. The diminution in amount of basic sulphate is continuous from the time of taking sample 7. Rapid action is shown by the table to have occurred when the furnace-door was opened—between the samples 9 and 10.

Sulphate of Silver.

No sulphate of silver was found in samples 1, 2, and 3, and but a faint trace in 4. From that time on, the amount increased

* Steinbeck, *Chem.-Anal., etc.*, p. 54.

until sample 11 was taken, at a temperature slightly above 750°, when the maximum was shown. No trace of either neutral or basic sulphate of copper remained in sample 11. The roasted matte was finally heated to 850° C., to determine whether the temperature could be safely raised to that point, as was shown to be true in the electric furnace. In this particular roast there was no necessity for proceeding beyond the time of sample 11, since, at that time, there remained no sulphates of copper to decompose. The loss due to the excessive heat was small, as seen by comparing the silver in samples 11 and 12.

The whole time occupied in the operation was 5 hours and 40 minutes: One hour in heating the furnace and matte to 350°, two hours and twenty minutes in forming sulphates, two hours in decomposing the sulphates of copper, and twenty minutes in heating to 850° C. after all the copper sulphates had disappeared.

Results of Roast No. 2.

Another roast of one and a half pounds of the same matte was carried through, and the entire operation effected in the oven-furnace. The temperature was raised more rapidly than in the former case, and the time during which the roasting proceeded was but three hours and ten minutes, a little more than half the time occupied in the previous operation. The roasting was completed in one operation. Two hours were taken to form sulphates, and these corresponded in amount to the similar compounds formed in the previous roast. Less than one hour was required to decompose the copper sulphates, the temperature during the dissociation period being much higher than it was during the same period in the former operation. Care was taken, however, not to heat the matte above 850° C. After all the copper sulphates had disappeared the charge was heated above 850° C. for fifteen minutes, the highest point reached being 910° C. The maximum silver sulphate occurred in sample 11 at 835°–845° C. This decreased rapidly after 850°–860° C. was attained; and in sample 13, taken at 910° C., the soluble silver compound amounted to less than one-half of that soluble at 845° C. in sample 11. Table XV. gives the direct results of the analyses of samples from this roast. Total copper and the reducing factors are shown in Table XVI., and the corrected results of analyses in Table XVII.

TABLE XV.—*Direct Results of Analyses of Samples.*

No. of Sample.	Time.	Temperature.	Cu as $CuSO_4$.	Fe as $FeSO_4$.	Basic Sulphates.	Silver. Oz. per Ton
		Deg. C.	Per cent	Per cent.	Per cent. SO_4.	
1	After 30 min.	450	6.2	0.8	3.21	....
2	" 45 "	560	9.4	0.8	4.88	....
3	" 80 "	630	10.9	0.5	6.21	....
4	" 90 "	650	11.2	0.45	7.72	trace.
5	" 100 "	670	11.4	0.3	12.23	trace.
6	" 110 "	680–690	11.7	0.26	15.12	26.25
7	" 130 "	735–750	10.1	0.13	12.48	38.14
8	" 140 "	785–795	8.6	trace.	11.68	54.25
9	" 150 "	800–810	6.5	None.	10.52	67.68
10	" 160 "	815–830	4.5	....	8.51	79.0
11	" 165 "	835–845	2.1	....	1.44	90.0
12	" 175 "	855–870	None.	....	trace.	77.2
13	" 190 "	910	None.	....	None.	43.2

TABLE XVI.—*Total Copper and Reducing Factors.*

No. of Sample.	Total Copper.	Reducing Factor.
	Per cent.	
Original Matte.	50.8	1.00
1	44.4	1.14
2	43.3	1.17
3	42.8	1.19
4	41.2	1.23
5	40.6	1.25
6	38.5	1.32
7	38.8	1.30
8	39.0	1.29
9	39.4	1.28
10	44.5	1.14
11	49.5	1.01
12	51.4	0.99
13	51.4	0.99

TABLE XVII.—*Corrected Results of Analyses of Samples.*

No. of Sample.	Time.	Temperature.	Cu as $CuSO_4$.	Fe as $FeSO_4$.	Basic Sulphates.	Silver oz. per Ton = Per ct.
		Deg. C.	Per cent.	Per cent.	Per cent.	
1	After 30 min.	450	7.07	0.91	3.65	....
2	" 45 "	560	10.99	0.94	5.71	....
3	" 80 "	630	12.97	0.59	7.39	....
4	" 90 "	650	13.77	0.55	9.49	....
5	" 100 "	670	14.25	0.37	15.29	trace.
6	" 110 "	680–690	15.44	0.34	19.96	34.65
7	" 130 "	735–750	13.13	0.17	16.22	49.58
8	" 140 "	785–795	11.09	trace.	14.07	69.48
9	" 150 "	800–810	8.32	....	13.46	86.63
10	" 160 "	815–830	5.03	....	9.81	90.06
11	" 165 "	835–845	2.12	....	1.45	90.90
12	" 175 "	855–870	None.	....	trace.	76.42
13	" 190 "	910	None.	....	None.	42.76

Basic Sulphate of Copper.

The basic sulphate of copper is practically insoluble in distilled water, hot or cold; but in water containing neutral copper sulphate in solution this basic salt is soluble to a considerable degree. This fact partly accounts for the maximum soluble sulphate coming at a temperature above that at which the neutral sulphate begins to decompose (viz., 653° C.). The basic salt increases rapidly from the time the temperature of dissociation of the neutral salt is reached (sample 4); and the solution of neutral sulphate, acting upon this increased quantity of basic sulphate, gives the maximum soluble sulphate at a stage when the actual amount of neutral salt in the roasting mass has passed its maximum. This explanation applies to the other roasts, whose analyses are given in this paper.

Roasting of Matte Free from Iron.

Copper sulphide was prepared by treating a solution of copper sulphate with hydrogen sulphide from a generator. The sulphide was collected and dried. To 175 grammes of this black sulphide was added a small quantity of silver sulphide, prepared by precipitation from a solution of silver nitrate. These sulphides were mixed and placed in a fire-clay crucible, and fused in a gas crucible furnace. The molten matte was poured into cold water contained in an earthen jar of 5 gallons capacity. The granulated mass was ground in a mortar to pass through a 60-mesh screen. The silver and copper contents were as follows: Copper, 74.8 per cent.; silver, 235 oz. to the ton. One hundred grammes of this matte was placed in a fire-clay roasting-dish and heated in the muffle-furnace. The couple of the pyrometer was placed within the roasting-charge. Though but forty minutes was occupied in reaching the temperature of maximum copper sulphates, and no iron sulphate was present to assist in forming these compounds, still the amount formed, as shown in sample 1, was considerable. Table XVIII. gives the corrected results of analyses of samples taken at successive stages in the process. The results of this roast on copper matte free from iron correspond with those of the iron-copper matte given in Tables XIV. and XVII.

In the operation of roasting the argentiferous copper mattes

TABLE XVIII.—*Corrected Results of Analyses of Samples.*

No. of Sample.	Time.	Temperature.	Total Copper.	Reducing Factor.	Cu as $CuSO_4$.	Basic Sulphate.	Silver	Silver Sulphate.	Total Silver.
		Deg. C.	Per ct.		Per ct of wh'le	Per ct. SO_4.	Oz. per Ton.	Per ct.	Oz per Ton.
Original Matte...		....	74.80	1.000	....	....	....	....	235
1	After 40 min.	675–685	65.13	1.147	8.44	....	trace	....	....
2	" 70 "	750–760	66.58	1.123	5.94	11.66	184.2	78.3	....
3	" 87 "	790–800	67.12	1.114	5.48	10.57	189.4	80.6	....
4	" 97 "	810–815	69.53	1.076	2.81	4.12	201.2	85.6	....
5	" 107 "	845–850	75.00	.998	....	trace	211.5	90.0	....
6	" 117 "	870–875	77.31	.967	....	....	145.8	61.9	....
7	" 130 "	890–900	77.30	.967	....	....	49.9	21.2	....

it was found desirable to have an excess of air,* not only to facilitate the production of sulphates, but also for the removal of the gaseous products of their decomposition. The more rapid the dissociation, the less the time during which the roasting matte is held at a high temperature, and consequently the less the loss in silver. Above 655° C. the sulphate of silver is in the liquid state, and experiments seem to indicate a slow but continuous loss—possibly by volatilization as sulphate—after the substance is thoroughly fused, even though the temperature is not raised to the point at which it decomposes.

On the whole, the results of the roasting operation confirmed the facts determined with the electric furnace. To decompose the sulphates of copper, a temperature above 700° C. was required. The rate of decomposition of the sulphates was more rapid as the temperature was raised above 700° C.; but there was found to be no necessity for heating the charge above 800° C. to complete the process. Care needed to be taken not to allow the furnace in any part to become heated above 850° C.

By the aid of a reliable pyrometer, and with a range of 150° C. (= 270° F.) between the temperature at which the basic sulphate of copper begins to change to copper oxide and the temperature to which silver sulphate can be safely heated, the workman in charge of the furnace should be able to conduct the operation of roasting, in the Ziervogel process, without undue loss of silver. Having in mind the facts set forth in this

* "The Metallurgy of Argentiferous Copper Compounds," by H. M. Howe, in *Production of Gold and Silver in the United States*, Burchard, 1883, p. 757.

paper, the superintendent should be able to get good results in the Ziervogel process without the aid of expensive skilled labor in the management of the roasting-furnace.

Resulphatizing the Metallic Silver Resulting from the Decomposition of the Silver Sulphate by Excessive Heating.

The iron-copper matte of the composition, given on page 76, was roasted in the oven-furnace until all the sulphates of iron and copper were decomposed. The temperature was allowed to rise to 905° C., and, as a result, much of the silver sulphate was decomposed, with a corresponding precipitation of metallic silver. Analysis of the dead-roasted charge showed but 35.2 per cent. of the entire silver to be soluble as sulphate.

A portion of this roasted material was mixed with 5 per cent. of its weight of dehydrated ferrous sulphate, and heated in a roasting-dish in the muffle-furnace for fifteen minutes. The temperature was allowed to rise slowly above 590° C., and the highest point attained was 750° C.

0.6 A.T. of the material was weighed out, and the sulphate of silver dissolved by means of hot water, as already described. The solution was titrated for silver with ammonium-sulpho-cyanate of such strength that 1 c.c. corresponded to 0.0047 g. of silver. 11.6 c.c. of the solution was required, showing 0.0545 grammes of silver, soluble as sulphate, in the 0.6 A.T. of the roasted matte, or 90.8 oz. per ton.

The percentage of soluble sulphate was thus increased from 35.2 to 90.8 by means of the ferrous sulphate added to the charge.

A second experiment was carried through with a quantity of the same dead-roasted matte, containing 35.2 oz. silver per ton, soluble in hot water. A relatively larger amount of ferrous sulphate was added to the charge, and the roasting occupied more time. The results of the titration with ammonium-sulpho-cyanate showed 93.8 oz. silver per ton, soluble in hot water.

Another sample of the 100-oz. matte which had been dead-roasted, but which had been heated only to a temperature of 880° C. and contained 64.4 oz. of silver soluble as sulphate, was heated in the same manner as described above. After the re-

sulphatizing by the ferrous sulphate, the percentage of silver soluble as sulphate had been raised from 64.4 to 91.3.

From these experiments it is seen that the metallic silver, in the finely-divided condition in which it exists in the over-roasted matte, is readily resulphatized by the sulphuric anhydride evolved from the decomposing ferrous sulphate. No doubt other decomposable sulphates would accomplish similar results, providing their dissociation occurs at a sufficiently low temperature. The sulphates of sodium and potassium, as such, do not readily decompose by heat alone. Ferrous sulphate is a convenient compound to employ, not only because of its comparative cheapness, but because it begins to decompose at a temperature far below that to which the sulphate of silver can be safely heated. Though it begins to decompose below 600° C., the decomposition is not rapid until 650° to 700° C. is attained. If the mixture of over-roasted matte and ferrous sulphate be rapidly heated to a temperature near 700° C.—*i.e.*, that at which the basic sulphate dissociates—there will be little cupric sulphate formed, but the sulphuric anhydride fumes will react directly upon the metallic silver. There will, therefore, be no necessity for raising the temperature or prolonging the time in order to decompose the sulphates of copper, and thereby running the risk of again depositing the silver of the sulphate in the metallic state.

The Auditing of a Mining Company's Accounts.

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(New York and Philadelphia Meeting, February and May, 1902.)

THE comprehensive audit of the accounts of a mining company is extremely important in its relations to the legal situation and obligations of the corporation, the personal liability of the directors, and the interests of the investing public. A consideration of the subject as affecting the professional duties and fixing the responsibility of a mining engineer engaged in the expert examination of a mine or in charge of mining operations, is equally important, though this phase of the question is not often presented systematically.

Business customs have pretty clearly established the purposes and principles of an audit. But in the absence of statutes compelling strict periodic investigation of their financial affairs, many companies of excellent repute do not avail themselves of the advantages afforded by such an audit. On the other hand, the failure of many companies to make public the true state of their affairs by means of an adequate financial audit is the frequent cause of loss to investors. The value to both parties of a systematic and thorough examination of company accounts is becoming, however, more and more generally appreciated; and it is to be hoped that this may result in suitable legislation, requiring an annual audit of the accounts and financial affairs of all private corporations, and providing for the license and registration of competent, professional accountants. Such a rule would tend to eliminate that element of fraud and the consequent danger of loss to which the stockholder is exposed, when he is forced to rely upon officials for information relative to the standing of the company in which he is interested. True, a financial audit offers no protection against the false or erroneous statements of the condition of the mine itself. Nor will it assist stockholders in penetrating the mysterious reticence or paradoxical ambiguity with which boards of directors muzzle and muffle their reports regarding the present condition and future prospects of their mines—a policy of concealment and of mystification which operates, as positively as tangible fraud, to enhance the element of speculation present, in varying degree, in all mining enterprises.

But it is safe to say that in a mining venture, where risk is always expected, capital will more readily seek investment, and stockholders will more cheerfully assume risk and more willingly support any reasonable policy of a board of directors, if good faith and frankness are shown by regular and comprehensive reports and audits.

The Value of an Audit.

The value of a commercial or general business audit depends upon its purpose, its minuteness of detail, the authority and responsibility of the auditor, and the scope of his instructions. The duties of an English chartered accountant, acting as an auditor, are defined, and, to a certain extent, specified by the

"Companies Act" of 1862, which compels an annual audit of all registered joint-stock companies. The United States law has a similar provision, compelling the examination of all national banks by qualified government examiners. But so far as other corporations of private enterprise are concerned, an auditor's duty consists in performing that for which he is employed, and he is responsible to his employer only. If his appointment depends upon the good will of the company's officials, the presumption is that he will act as their agent rather than as the agent of the stockholders; or, if he be engaged to examine accounts and report upon some particular question, it is not likely that he will take it upon himself to extend his examination and report to cover more than that question. For instance, if he is asked to ascertain whether a reported reserve-fund is real, or exists upon paper only, and how the said fund is invested, or to say whether, in his opinion, the working-capital is sufficient, he would discharge his duty by a partial examination of the accounts and a report upon the one question submitted to him. But when a complete audit of the accounts of a mining company is required for the purpose of presenting to the stockholders a statement exhibiting the financial position of the company, and furnishing data which may possibly assist in deciding upon future operations, the auditor, if employed as the agent of the stockholders, will exhaustively examine and check all books of account and all the financial affairs of the company.

Inspection of Accounts by Mining Engineers.

In examining a mining property for clients who contemplate purchase, the mining engineer often finds it necessary to make an exhaustive search through the accounts and records previously kept by the owners of the mine. This is, perhaps, most frequently the case when it is desired to ascertain the actual cost of mining at a producing mine. If such a mine has been operating sufficiently long to have established a fairly uniform cost, he may be warranted in accepting the figures given by the owners, supplemented by only a cursory inspection of the accounts. But in cases of doubt or suspicion it may be desirable to verify the figures given. While some mining companies, in calculating the cost per ton of the ore extracted, include all expenses

of dead-work, development, exploration, etc., many others state as the cost of extraction-work the actual expenditure for stoping and hoisting only, treating the development-work, especially in shaft-sinking, as a "capital" expenditure. Practice in classifying expenditures in this respect, and the arrangement of accounts relative to mine-costs, is so varied that an engineer can satisfy himself only by an examination of the books, if he would know what items are included in the costs. Particularly in considering a "low-grade" proposition, where accurate data are absolutely necessary, it is an immense advantage to be able to determine in detail, by personal investigation, the actual facts.

Of course, the present worth of a mine cannot be determined by the amount of its past dividends; yet, in many instances, the gross earnings, as represented by the tonnage and value of ore already produced, may have a signal importance in considering the future relation of profits to operating-expenses.

The value of the product of the various stopes, as shown by the record of ore-sales, affords the closest possible check upon the values obtained by sampling the several ore-bodies from which ore has been shipped. A determination of the tonnage and value of "ore in sight" is naturally the first consideration of the engineer. But in his judgment of the mine as an investment, the item of costs is a factor of equal importance. From no other source can he obtain such accurate detailed information relative to the costs and charges of mining as from the books and past records of the mine under examination.

The Conduct of an Audit.

Since the mining business is so radically subject to local conditions, it is to be expected that the forms of records and accounts will be varied to suit each special case. And, although the principles of accounting are fixed, there exists almost as great a diversity in the systems of accounts in use as in the forms and registers employed. With due appreciation of the difficulties likely to arise from this lack of uniformity, the following general suggestions are offered as to the manner of conducting a practical audit of mining accounts.

In the majority of instances, a mine is owned and operated by a corporation, the main or financial office of which is far

from the mine. This makes it practically necessary to consider two sets of accounts: those conducted at the mine, which directly concern the mine-management; and those belonging to the province of the secretary, which constitute the permanent financial records of the company. The mine-office accounts, in full detail, together with vouchers, are usually forwarded at regular intervals to the main office, where a general audit is made, there being at the mine-office but a local audit or checking of the accounts. For the present purpose, however, it may be assumed that all the records are kept and all the accounts conducted in the office at the mine.

List of Books.—In order to plan an intelligent dissection of the accounts, it is necessary to know how they are put together. To this end it will be well, first, to secure from the person in charge an explanation of the system employed, with a list and description of the books used. Indispensable, of course, to the double-entry set of books usually kept at a mine, are the cash-book, journal and general ledger. In addition to these, and to the several subordinate record-books, blotters, etc., which convenience demands, a well-regulated system of mine-accounts ought to include books of ore-shipments and of mining-costs. The former should show in detail the lots of ore sold at the mine or shipped, identifying each lot by number, and giving date of shipment, date of payment, weights, terms of settlement, values, and net returns, and also specifying the stope or heading in the mine from which the lot was mined. The costs-book, in the nature of an independent or special ledger, is kept to relieve the general ledger of the burden of the many accounts necessary when accurate record is made of the costs chargeable to each separate place of working in the mine. Cost-keeping is one of the most important departments of mine-accounting; and the costs-book, when properly conducted, is a regular monthly statement and analysis of costs, itemizing the cost of labor, material and supplies, and distributing the power- and operating-charges, and the indirect or fixed and general expenses. Moreover, it is also a special ledger, containing an account with each place of working, in which are charged monthly the itemized costs as above, and from which are carried, by journal-entry, the totals only of the month's expenses to a "Costs of Mining" account in the general ledger.

The general ledger is considered the principal book, being the source from which is obtained all classified information relative to the financial condition of the business. But it may be well to suggest that, although this book is the receptacle for all transactions, in whatever book the entries may originate, the ledger itself is generally ignored by courts of law. The "book of original entry," legally defined as that in which the preliminary record or entry of a transaction is first written, is accepted as authority on all questions involved in a transaction or in a series of transactions.

Capital-Stock; Treasury-Stock; Working-Capital.—The capital-stock comprises the full amount of the capital authorized to be raised by the charter or articles of incorporation. The treasury-stock is the stock, over and above the amount subscribed and paid for when the company is organized, which is set aside and held by the treasurer, to be sold for the purpose of securing funds to carry on operations. If the entire capital-stock was subscribed and the whole amount paid in was absorbed in the purchase of the mine and the necessary equipment, and further capital is needed to carry on work, the stockholders may, by agreement among themselves, instead of increasing the capital-stock, donate *pro rata* a certain number of shares to be held and sold by the treasurer for working-capital. A working-capital account is sometimes opened with a credit of a certain amount of the subscribed stock or capital, this sum being set apart for use in prosecuting the development of the mine, etc. These accounts should probably receive first attention. An examination of all entries should be made from their origin in the auxiliary books to their final posting in the general ledger. The principal books auxiliary to the general account-books of a corporation are the subscription-book, installment-book, transfer-book and stock-ledger. The stock-ledger is used solely for carrying accounts with stockholders of their respective holdings in the company. All the other books mentioned are books of original entry, subsidiary to the stock-ledger. Examination of these books should establish the fact that the capital-stock account in the general ledger is credited with the full amount of the authorized capital, whether paid up or not. If it has not been fully paid, an open subscription-account will probably be found in the ledger, exhibiting

the amount of stock subscribed and not paid for. The amount issued and paid in should correspond with the aggregate holdings as shown on the stock-ledger. A close scrutiny of the treasury-stock account, or working-capital account, if either exist, should be made, to ascertain the character of the account, and how it was created. If there is treasury-stock on hand, carried as an asset, the amount should be noted.

Cash-Receipts.—A complete audit involves a careful and systematic checking of each and every individual transaction during the period under audit. The opening and subsequent entries covering cash-receipts for capital-stock subscriptions paid, and for treasury-stock sold, should be examined and checked. The records of sales of treasury-stock should be critically examined, and the entries traced to their final exhibit on the books. If stock is sold at par, "Cash" will, of course, show the proper debit-entry for the amount received. If disposed of at less than par, or if sold at a premium, the entries covering the balance or difference between the amount received and the nominal or par value of the stock, as well as the cash entry, should be carefully investigated. Strictly speaking, the discount on stock sold at less than par is not a loss, nor is the premium on stock sold above par a gain, of the business proper; and the amount in either case will probably be covered into the working-capital rather than the profit-and-loss account. Frequently, however, especially if a profit has been realized on such sale, the amount is carried directly into Profit and Loss. Practice varies considerably in the conduct of accounts relating to treasury-stock and working-capital. But in whatever manner transactions of this nature are recorded, an audit will prove its efficiency if it determines that fictitious values are not given in the accounts representing resources, actual liabilities, expenses, or any other account affecting profit and loss.

Practically, the only revenue of a mine is derived from the sale of its product, in whatever form (crude ore, concentrates, matte, bullion, etc.) it may be marketed. All items of cash, as shown on the cash-book, should be checked; but this one principal item should be verified by comparing the receipts, as entered, with the ore-shipment register, and with the settlement-sheets or statements rendered by the smelter or other

purchaser. Such a statement is rendered for each shipment separately by all ore-purchasers, or, in the case of a company smelting the ores from its own mine to crude bullion or matte, by the refinery to which this product is sold.

Cash Disbursements.—All items of cash disbursement should be checked and compared with the vouchers or proofs of payment.

If the "voucher-system" is employed, and transactions are recorded by classification in a voucher-journal, from which the totals of like debits and credits, instead of individual items, are posted, the work of checking and comparing the itemized expenditures will be confined to this book of first entry. The footings of this journal are then verified, and the posting of aggregate totals is regularly checked.

A critical examination of the vouchers should be made to ascertain whether the payments made were properly authorized and certified.

Pay-rolls should be examined to see that they are properly and duly signed by employees, and that the totals of each are correctly entered.

The balance of cash shown by the books should agree with the amount of cash on hand and in bank, less the amount of outstanding checks not yet presented for payment.

After the purely mechanical checking of all entries in and postings from the cash-book, journal, etc., and the verification of their arithmetical accuracy, the next, and essentially the most important, step is to trace each entry from its inception to its final posting, with the view of detecting errors and irregularities, whether of ignorance or of intentional fraud.

This critical examination is of considerable moment, particularly if the audit is made under conditions exacting a close discrimination between expenditures of capital and of revenue.

Capital.—Capital-expenditure accounts are debited with all disbursements which result in the acquirement of something of permanent value.

Such entries require very careful inspection, not merely to prove clerical accuracy in recording the transactions, and the vouchers and receipts covering them, but also the legitimacy of their classification as capital-expenditures. A systematic in-

vestigation of the amounts carried to capital, and of all entries of amounts expended and covered into the accounts of buildings, plants, machinery, equipment, air-pipe lines, water-mains, etc., etc., should afford an approximate verification of the correctness of these property-accounts, and put to proof the fairness of the valuation of the several plants carried as assets.

These accounts should be also scrutinized, to see that they are duly credited with amounts written off, from time to time, for depreciation. Such amounts, taken out of income for deterioration of plant, are usually debited to profit-and-loss direct, but are sometimes carried by a charge to a depreciation-account.

A close discrimination between expenses properly chargeable to capital and to revenue, respectively, is of vital importance; for it is apparent that if too great a portion of the expense of any year be charged against capital, then the current expense will appear smaller and the profit correspondingly greater. On the other hand, if the entire cost of plant and equipment, or of improvements, which, for all practical purposes, may be considered of permanent value, is charged against the operating-expense or cost of mining of any year, a true profit with respect to the ordinary working-expenses and receipts may be made to appear as a loss. If the whole, or any portion, of the development-work of a mine for any year be charged to capital and the current operating-expense be relieved of this cost, the apparent profit will be unduly increased.

In the business of mining, custom has not yet established a uniform method of treating expenditures for renewals and repairs of machinery, plant and equipment. In fact, the question of distinguishing between capital and revenue for sums expended in the original purchase, enlargements and improvements of plants is a matter of individual concern and choice. Some companies treat every expenditure for machinery and equipment as fairly chargeable to the cost of mining for the year during which the purchase was made. Practically, this method may be said to be correct; since the sums so expended are part of the expense of mining, and must eventually be repaid by the revenue derived from the sale of the mine's product. Other companies are too prone to treat as capital not only the original purchase-price, but all sums expended for

improvements, and for renewals and repairs as well. And some companies do, while others do not, make provision for depreciation. In any event, an examination of the accounts should prove that the aggregate amount appearing in capital-accounts as expended for machinery, equipment, etc., is represented by plant of that value, maintained in efficient repair.

As stated, an approximate verification of these amounts can be arrived at by tracing from their source all entries for items so charged. For example, in case a mining-plant is purchased and erected under contract, it is easy to determine its original value by reference to the contract. The erection of plants, the installing of machinery, etc., when done by a company by day's labor, involve a careful consideration of the cost of labor, as well as of material and supplies.

It must be confessed that the wages-account is the most difficult of all to check effectually, especially in trying to distinguish between capital- and revenue-expenditures, when mining operations and construction are carried on simultaneously, and more especially when a company has no system of keeping and correctly recording amounts expended for wages. Where such a system exists, and where the records of one department are examined and checked by another and independent department, it will not be so troublesome to arrive at a comparatively accurate proving of the correctness of all wages charged to capital.

Revenue.—In a mining enterprise of any magnitude the debit-side of this account represents the expenditure of considerable money. An audit to determine the actual amount, and the correctness of the entries, of expenditure of revenue must be very comprehensive.

The vouchers and receipts, in addition to the checking on the cash-book, must be critically inspected, and the classification and distribution of the expense represented by each voucher must be verified.

Mining-supplies purchased are charged to revenue when used, not necessarily when paid for. This requires an exhaustive investigation into the nature and conduct of the stores-accounts, and a complete checking of these accounts, to make sure that all supplies taken from stores are properly charged, when credited to the stores-account. The entries covering

these transactions should be gone into pretty thoroughly. The prices charged for supplies consumed should be compared with the purchase-price and the cost as stated in inventory. An inventory ought to be taken of all material and supplies on hand, the values being compared with the purchase-prices, and the total with the aggregate of the various stores-accounts on the books.

Wages, salaries, and all fixed and general expenses, such as taxes, insurance, etc., are direct cash-disbursements. All these items, with the possible exception of wages, can be effectually tested by comparing with the vouchers, and by reference, when necessary, to the authority for the payment. For example, the correctness of salaries paid could be ascertained from the directors who had the fixing of salaries; and of taxes, by comparing the payments with the demands of the government, etc.

In the matter of wages it is impracticable to verify all the items on the pay-rolls which go to make up the aggregate expenditure for labor. The distribution and legitimate "expensing" of the cost of labor can be fairly tested as explained; but an auditor may be obliged to rely to a considerable extent upon the system of inter-staff corroboration referred to above, and upon the certificate of an official in authority, as to the veracity of the various pay-rolls.

If all accounts representing the operating-, fixed and general expense of the business are carried into one account, "Costs of Mining," at regular intervals, a comparison of the entries in this account with the mining-costs book will facilitate a verification of the aggregate expenditure chargeable to revenue.

Personal Accounts.—Personal accounts, accounts and bills receivable, and accounts and bills payable, should be examined carefully. In the business of mining, accounts of this nature are not frequent, and liability of loss from bad debts or doubtful accounts is limited. Such accounts, and the contingency of such loss, however, should be considered. The amount of accounts due and bills payable, as shown on the books, should be verified and taken into calculation in determining the gains or losses for the period under audit.

Financial Statement.—The task of checking and verifying all book-transactions being completed, the footings of all accounts in the ledger, whether closed or still operative, should be tested,

balances verified, and a trial-balance taken. This trial-balance proving the correctness of the ledger, it is now in order to prepare a statement of assets and liabilities, and a statement of profit and loss.

The financial condition of the company should be very clearly set forth in this financial statement, the balance-sheet exhibiting:

Property and Assets.	*Capital and Liabilities.*
1. *Property*, showing mines and mineral claims, and other real property.	1. *Capital Stock*, showing in detail the number of shares; amount paid up; amount, if any, remaining unpaid; amount and nature of arrear of calls, particulars of forfeited shares, etc.
2. *Improvements*, showing buildings, machinery, plants, equipment, etc.; also stores and supplies on hand.	2. *Debts and Liabilities* of the company, showing the amount of debts owed by the company, enumerating the same, and distinguishing actual from contingent liabilities, etc. These contingent liabilities, such as claims against the company not acknowledged as debts, or moneys for which the company is contingently liable, should be stated; but only the amount of acknowledged debt is carried out as a liability.
3. *Cash and Investments*, showing amount of cash on hand and in bank, the nature of investments, rates of interest, etc.	3. *Reserve-Fund*, showing the amount set aside from profits to meet contingencies.
4. *Debts Owing to the Company*, showing all debts, accounts and bills receivable.	4. *Profit and Loss*, showing the disposable balance for payment of dividends, etc.

The statement of profit and loss should state specifically upon what accounts losses have been sustained, and detail the accounts through which profits have been realized. In calculating the gains and losses, it must be borne in mind that the loss or gain of a mining-venture for any given period is not merely the difference between the receipts for ores sold and the costs of mining. Depreciation must always be taken into consideration.

Redemption of Capital.

In connection with an audit it is essential that the questions of depreciation, dividends, surplus and redemption of capital be taken into account. Most industrial enterprises involve the same elementary principles. But there are considerations in mining which do not affect other kinds of business.

A mine cannot be said to be a permanent source of wealth. Every ton of ore mined and marketed involves a depreciation in the value of the property which cannot be repaired. Hence, during the life of a mine, not only must interest be realized upon the capital invested, but the capital itself must be recovered, if the venture is to prove successful. In this respect, depreciation and dividends may be considered as different causes operating to the same end, namely, the diminution of the value of the property.

Depreciation.—Generally speaking, the loss upon assets which are diminishing in value is called depreciation. As applied to plants, equipment, mining machinery, etc. (provided the original cost of these items is not treated as a portion of the current operating-expense, and so charged at time of purchase), a certain sum, estimated upon the life of the plant, should be charged against the gross revenue of each year, to replace the capital destroyed or reduced by wear and tear. The method of treating sums expended for plant as current expense is manifestly unfair, both to the management desirous of making a record in the matter of mine-costs and to the present stockholders; for, in the early stages of a mine, when most of the equipment is purchased, costs will be exaggerated, and dividends which might otherwise be paid may be deferred, by reason of this abnormal increase in the current-expense account. But, since the life of mining machinery is comparatively short, and there is practically no residual value, in case the mine is abandoned as worked out, or the machinery has to be replaced by a plant of greater capacity, it is not only prudent but absolutely necessary that some provision be made to redeem its cost.

Depreciation, as applied to the redemption of the capital invested in a mine, provides for the writing off of a certain sum each year, estimated upon the life of a mine, to accumulate a sinking-fund for this purpose.

In the business of mining, however much may be said in

favor of some method of accumulating a sinking-fund, such a fund is seldom, if ever, provided for. The individual stockholder usually thinks that he would prefer to have his capital returned to him as fast as it may be taken from the mine, rather than await the accumulation of a fund sufficient to redeem the whole capital. To this end the custom prevails, and will probably be considered the better method, so far as mining is concerned, of repaying capital by dividends. By means of dividends, or, as they might properly be called, *enlarged* dividends, the stockholder, after calculating a fair interest on his investment, can consider the sums received over and above this interest as repayments of the principal of his investment.

This method may be subject to some question, since there are few (except those who have given special thought to the matter) who properly appreciate the difference between a dividend which is purely a distribution of profits and a dividend which is intended to repay capital. Then there is this contingency to face: in the case of a successful mining enterprise it may be found that the full amount of the company's capital is carried as a liability, when, in fact, it has all been repaid in the shape of dividends; while, on the other side of the balance-sheet, the mine, valued at its original cost and worth, is still shown.

The amount paid in dividends in this way each year may be estimated, or rather will depend, upon the amount of output and the profit realized upon the sale of product.

Dividends.—The term dividend, as generally accepted, means a sum which a corporation sets aside from its profits to be divided among its members. It is a fundamental rule that dividends shall not be declared or paid when a company is insolvent, or the payment of which renders a company insolvent. A dividend must be declared from realized, and not from estimated, profits. The violation of this rule is not common. But it too frequently happens that when profit does not follow on the heels of promise the directors of a company, anxious to appease the importunity of stockholders, are led to ignore one of the most important precepts of financial prudence. Under this constraint they declare and pay dividends without first having provided a surplus or reserve-fund; that is, a special fund of profits set aside for the purpose of meeting contingencies, or of equalizing dividends.

Reserve-Fund.—If such a fund, set apart from current income, or created by withholding a small percentage of the annual net earnings, is shown upon the books, this account should be examined by the auditor, and its accuracy should be tested. The amount should be held, either in actual cash on hand, or on special deposit in bank, or invested in safe and readily convertible securities. A reserve-fund once established should be drawn upon only in case of urgent necessity, or to meet exceptional and temporary reverses in profits.

The history of the mining industry is replete with records of companies wrecked by adverse circumstances, by reason of the lack of means with which to carry exploration to a probable successful issue,—means which might have been provided at a time when the mine was earning regular profits. But with working-capital exhausted; stockholders reluctant to pay assessments or to render themselves personally liable for borrowed capital; the ore-reserves of the mine worked up to their limit, and no reserve-fund to meet the exigency, the mine is abandoned. And thus is recorded another mining failure which a little forethought and business prudence might have averted.

Again, it may occur that a mine in the full flush of prosperity is compelled to discontinue dividends for a period. There would be fewer disappointed stockholders, in this respect, if the policy of providing a surplus were rigidly insisted upon. Regular dividends could be continued, and a most distressing period in the affairs of a mining company could be safely tided over if, during its most profitable period, provision had been made for such a crisis.

General Remarks.

As has been observed, and will no doubt be confirmed by the experience of most mining engineers, there is a noticeable lack of uniformity in the systems of keeping mine-accounts. Such irregularity in the matter of registering and recording the routine of business details at the mine may be attributed to arbitrary local conditions. But the absence of uniform system in the more important departments of accounting, especially in the treatment of expenditures and in respect to mine-costs, must be ascribed, in part at least, to the scarcity of practical literature on the subject, and to the lack of active

discussion of the questions involved by those most vitally interested. In all other important productive industries, a considerable degree of conformity, not only in general system, but in details of shop-organization, cost-keeping, etc., has been established. This uniformity obtains, to a greater or less extent, even in manufacturing and mercantile pursuits, where processes and mechanical methods, locality, competition, and other conflicting influences, affect trade-conditions.

It is not intended to insist pedantically upon similarity of forms, methods, and like details, nor is it deemed necessary, on the other hand, to formulate the reasons for a generally uniform practice with respect to mine-accounts; but it may not be amiss to offer the opinion that in no other way can uniformity be secured except by concerted effort on the part of those who are actively interested in all that pertains to the economy of modern mining.

If, in connection with the many discussions relevant to the science and practice of mining, the business side of the question could receive the attention it deserves; if the interchange of ideas and opinions by those whose authority and interest are unquestioned were more frequent and general, reforms in this direction could be induced. By urging the adoption of a few conservative rules and principles of business which would tend to safeguard the commercial interests of mining, and by pressing the importance of a practicable uniformity in system and method, the engineering profession could increase the credit which it has already earned by what it has done to advance the business of mining from the plane of mere speculative gambling to its present high rank among the prosperous productive industries.

The Effect of Re-Heating upon the Coarse Structure of Over-Heated Steel.*

BY K. FREDRIK GORANSSON, SANDVIKEN, SWEDEN.

(New York and Philadelphia Meeting, February and May, 1902.)

INTRODUCTION.

The structure of steel, when rendered coarse by over-heating, is made fine by re-heating to a certain temperature, the determination of which has received much attention from eminent metallurgical authorities. Among these, I may particularly mention Prof. D. Tschernoff [Chernoff], who, about thirty years ago, studied this question in connection with his investigations on the structure of steel in general.†

Some years later, Mr. J. A. Brinell took up the inquiry, and arrived at many important conclusions, stated in his well-known rules on the treatment of steel.‡

These two gentlemen, however, based their reasoning chiefly upon the aspect of fractures—a method which, though it affords valuable information, does not readily reveal the different steps by which a change in structure takes place.

For further light on the subject, we owe much to more recent microscopic investigations, which have made us better acquainted with the internal structure of metals. Such an investigation, closely connected with the present subject, and made by Mr. John E. Stead a few years ago, was first published in 1898.§

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* SECRETARY'S NOTE.—This paper is substantially a thesis presented by the author in May, 1901, to the Faculty of Science of Columbia University, in New York. By consent of the Council, it is published also in the Swedish language by the *Jernkontoret* of Sweden. Members of the Institute will be interested to know that the author is the grandson of G. F. Göransson, whose experiments and improvements contributed essentially to the first practical success of the Bessemer process. (See the paper of Prof. Akerman, *Trans.*, xxii., 265.) R. W. R.

† "On the Manufacture of Steel and the Mode of Working It." (May, 1868.) Translated in *Proc. Inst. Mech. Eng.*, April, 1880, p. 286.

‡ "The Changes in the Texture of Steel on Heating and on Cooling," *Jernk. Ann.*, 1885, vol. xl., pp 9–38. Abstracted in *Jour. I. and S. Inst.*, 1886, No. 1, pp. 365–367. German translation in *Stahl u. Eisen*, vol. v., 611.

§ "The Crystalline Structure of Iron and Steel," *Jour. I. and S. Inst.*, 1898, No. 1, pp. 145–189; also, *The Metallographist*, vol. i., p. 289, Oct., 1898.

Regarding the cause of the disappearance of the coarse structure, as the result of annealing, Mr. Stead's observations led him to conclusions somewhat modifying, or, at least, rendering more complete, those of earlier investigators.

Mr. Brinell found that the refinement of structure takes place at the same temperature as the transformation of the cement-carbon into hardening-carbon, and concluded that the very violence of the transformation destroys all previous crystallization.

Mr. Stead, however, in examining the micro-structure of a piece of over-heated iron, containing 0.11 per cent. of carbon, which had been re-heated to 830° C., and then slowly cooled, found evidences of another factor, namely, the *diffusion of the carbon* into the grains of ferrite. He says:*

". . . . The pearlite was redistributed between the grains, and it could be easily seen to what point the carbon had diffused. . . . . Where the carbon has diffused into the ferrite, its coarse structure is broken up. We conclude from these results that the breaking up of the coarse structure in carbon-steels is not due only, as Brinell maintains, to the coincident change of cement- to hardening-carbon, but also to the carbon diffusing after such a change has been effected."

The aim of my investigation has been to collect additional facts which might be useful in the further study of this problem.

The steel I studied was a Swedish Bessemer steel, rolled to bars of $\frac{8}{16}$ by $\frac{9}{16}$ in. It contained:

	Per cent.
Carbon,	1.200
Phosphorus,	0.028
Silicon,	0.030
Sulphur,	0.002
Manganese,	0.230

The plan pursued in the investigation was: 1. To find the critical range of the steel; 2. To over-heat it, in order to get a coarse structure; 3. To re-heat it to various temperatures, at and about the critical range; 4. To study the effect of these heatings upon the micro-structure.

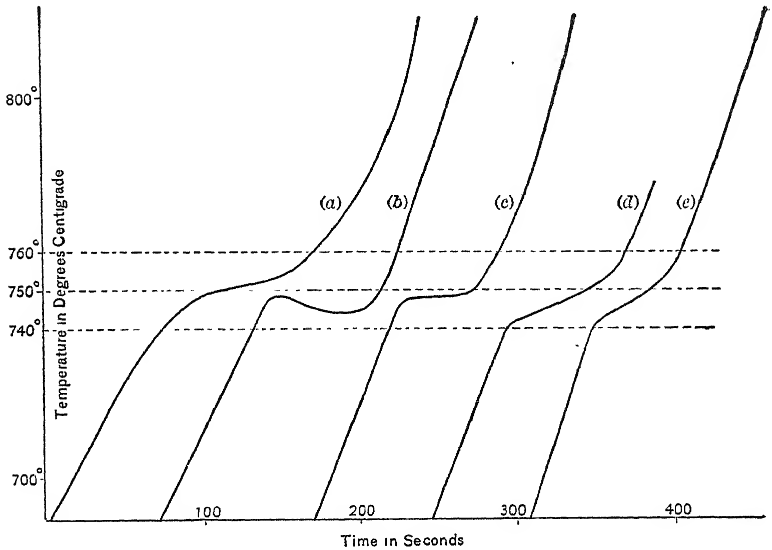
I. Heating- and Cooling-Curves.

In order to find the *critical range* of the steel, several heating- and cooling-curves were plotted. Some of these curves are

* *Loc. cit.*, p. 166.

shown in Figs. 1 and 2. Only one retardation-point could be detected within the range of the experiment (575° to 1060° C.). This retardation took place at 740° to 755° C. in heating, and at 690° to 700° C. in cooling, and seems to indicate the point "$A_{2\text{-}1}$;" that is, the temperature at which the eutectic pearlite changes into martensite, and *vice versa.**

FIG. 1.



Heating-Curves of Steel Containing 1.20 Per Cent. Carbon.

II. OVER-HEATING.

For over-heating, the bar was cut up into pieces of 3 in. in length, heated to about 1270° C., and then cooled slowly with the furnace, reaching a black heat after three-quarters of an hour. The over-heated steel was then cut into lengths of 1.5 in., and re-heated to the following temperatures:

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* In connection with these curves, I would say that in the case of one of the readings for the heating-curve (curve *b*, Fig. 1), the pyrometer indicated a *fall* of temperature at the retardation-point. The movement of the pyrometer was steady; and I do not think this apparent fall was caused by any defect of the instrument. In this special case Ac_1 seems to have been somewhat delayed; and perhaps this fact caused the transformation to be more violent than usual.

I do not think it would be proper to make general inferences from the appearance of these few curves; but I desire to point out that in those cases (*b* and *c*, Fig. 1) where the retardation began at a comparatively high temperature, it was completed at a comparatively low temperature.

T_{max}	Treatment.
920° C.,	Immediately cooled.
887° "	Immediately cooled.
850° "	Immediately cooled.
816° "	Immediately cooled.
790° "	Immediately cooled.
765° "	Kept at 760° for 1.5 h.
760° "	Immediately cooled.
748° "	Immediately cooled.
(Ac_1)	
725° "	Kept at 725° for 2 h.
725° "	Immediately cooled.
712° "	Kept at 695° for 1.5 h.
680° "	Kept at 660° for 2 h.
675° "	Immediately cooled.
675° "	Kept at 670° for 2 h.
625° "	Kept at 625° for 2 h.
575° "	Kept at 575° for 2 h.

The coolings were made naturally, in the air.

In examining the micro-structures, it was found that the over-heating had changed the original fine structure into a coarse net-work of cementite, enclosing large polygons of pearlite. The size of these polygons varied very much. In general, they were smallest in the center of the bar; but, even in a given region of the same specimen, the variation was considerable. This fact made accurate measurings of the size of the grains rather difficult.

The internal structure of the grains* showed well-laminated flakes of pearlite, with, here and there, isolated lumps and lines of cementite, which, in some specimens, had the form of straight needles, crossing each other apparently at an angle of 60°.

III. Re-Heating.

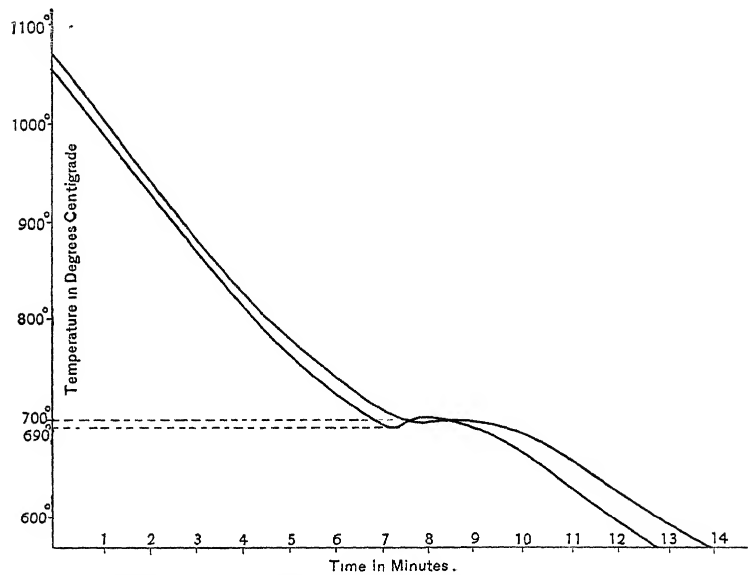
Re-heating to points below Ac_1 seemed to have no effect on the shape and size of the over-heated grains. Their internal structure, however, was slightly changed in specimens "soaked" for a couple of hours at a temperature closely below Ar_1 (but not at lower temperatures). This change consisted in the formation of rings of cementite, isolating small lumps of pearlite in the interior of the grains. It would seem that these rings were

* Secretary's Note.—The original text of this paper was accompanied with micro-photographs, which have not been reproduced for this publication of it. They are given in the version published in *Jernkontorets Annaler*, June, 1902.

caused by a flow of the cementite, which, during the soaking, might have had more time to arrange itself than it had during the continuous cooling of the over-heated piece. The rings had collected in certain parts of the grains, leaving other parts apparently unchanged. The laminated aspect of the pearlite was apparently the same after this soaking as before.*

When the re-heating passes Ac_1 the changes are more pronounced. A two-fold transformation seems to take place: (*a*) a sudden change in the internal structure of the grains; and (*b*) a gradual change in their boundaries.

Fig. 2.



Cooling-Curves of Steel Containing 1.20 Per Cent. Carbon.

a. The previous lamination of the pearlite is broken up and the new pearlite is rather badly laminated, if it can be called

* About nine months after the completion of the experiment here described, a piece of over-heated, but not re-heated, steel, which had not exhibited such rings upon the first examination, was re-examined, and was then found to contain them, although to a smaller extent than was shown in the re-heated specimens. The only new manipulation which this piece had undergone was repolishing and re-etching—the latter being performed with dilute nitric acid, in the same manner as before. This observation, if confirmed by similar ones, would indicate that the formation of the cementite rings takes place in cold steel, if sufficient time be allowed for it.

laminated at all. Etching with 20-per-cent. nitric acid makes it appear as a dark mass, covered with a multitude of small dots of cementite, looking like pin-holes. These dots are pretty uniformly distributed over the surface, but many of them show a tendency to arrange themselves into rings and short rows. In some places, even, the dots unite, making continuous lines instead of dotted ones; but this is not generally the case. Only when the re-heating temperature passes 800° C. do they show a stronger tendency to melt together. In that case, the union of some of the dots may effect a more definite lamination of the pearlite, while others form a net-work of cementite, enclosing a new set of grains inside the old ones. These new grains are rather small and irregular; but, as the temperature rises, they grow larger, and assume a polygonal form, accompanied by a more regular lamination of the pearlite.

b. As to the changes produced in the boundaries of the old grains, it may be said that, if re-heating barely passes the retardation point, it has no appreciable effect upon the old net-work of cementite; but, as the temperature rises still higher, the net-work becomes disconnected and loses itself in the finer net-work of the new grains above described. This change is very gradual, and is not completed until a temperature more than 100° C. above the retardation point has been reached. That the transformation is a question of temperature, rather than of time, is shown by the fact that, in specimens soaked at 760° C. for 1.5 h., the old net-work was still well-preserved.

IV. Theoretical Inferences.

The above observations seem to indicate that the destruction of the coarse net-work of cementite is caused by its carbon being dissolved in the martensite, and that the net-work surrounding the new grains is formed by the expulsion of cementite from the martensite as it is being cooled.

It is important to distinguish between the formation of the *grains* and the formation of the *net-work* of cementite between them, for it is probable (and is generally held) that the grains exist in the martensite even at the highest temperatures, and that they are caused by a tendency of the particles of martensite to arrange themselves in certain directions. It also seems that, the higher the temperature, the more effect has this tendency, and the larger are the resulting grains.

During the cooling, cementite is expelled from the martensite, and seems to collect between the grains, broaden the boundaries, and enable us to detect them by the microscope.

Now, the cementite expelled in the over-heated steel forms a much coarser net-work than that expelled in the re-heated steel. This fact may indicate that the polarization of the martensite into coarse grains has been destroyed between the two processes of expulsion.*

When should this destruction of the polarization have taken place? It seems to me that we have two possibilities: Either the destruction of the polarization might have taken place when the re-heating reached Ac_1—in which case we approach the view held by Mr. Brinell; or the destruction of the polarization might have already taken place when the over-heated steel, during its cooling, passed the recalescence-point. According to this hypothesis, the coarse net-work of cementite was then already formed, and served to preserve the coarse structure of the steel, even though the polarization of the particles no longer existed.†

V. Practical Conclusions.

To the practical question, What re-heating temperature is needed in order to break up the coarse structure? the reply, on the above theory, would be that we have to heat the steel to the point where *all* the cementite has been dissolved by the martensite. And this seems to be, in fact, the case; for, in the experiments here described, where the steel had been re-heated to 850° C., there were many of the old large grains remaining; but where the re-heating had reached 887° C., the large grains had completely disappeared.

According to the curves of Sir W. C. Roberts-Austen and of Prof. Roozeboom,‡ the cementite of a 1.20-per-cent. carbon-

* A fact which possibly might indicate a destruction of this polarization is the dotted or imperfectly laminated aspect of pearlite formed in cooling from temperatures slightly above the retardation-point. We do not yet know the cause of the lamination of pearlite; but if it has something to do with a polarization of the martensite, it would seem natural that an imperfect polarization, such as might be produced at the lower temperatures, would go hand-in-hand with an imperfect lamination of the pearlite.

† This supposition is favored by the rearrangement of the cementite, already mentioned, in specimens re-heated to points closely *below* Ac_1 and kept there for some time.

‡ *The Metallographist*, vol. iv., p. 154, April, 1901.

steel begins to fall out from the martensite at about 870° to 880° C., that is, at a temperature intermediate between the re-heating temperatures of 850° C. and 887°C., determined in these experiments.

Whether this theory is valid for hypo-eutectic steels also, future experiments must decide. It may, however, be of interest to point out that Mr. Stead, in the experiments on the crystalline structure of iron and steel, reported in his paper already cited, found a refinement of the grains at 900° C. for steel of 0.01 per cent., and at 870° C. for steel of 0.11 per cent. carbon, and that these two points correspond to the temperatures at which, for such steels respectively, the ferrite begins to fall out from the martensite.

POSTSCRIPT.

By Henry M. Howe, New York City.

The work described in this paper was undertaken as a step toward studying the coarsening of the grain of steel which takes place as the temperature is progressively raised above the critical range, and the refining of the grain by re-heating to that range. A recapitulation of the points shown by the investigation will facilitate an explanation of their significance.

When steel, the grain of which has been made extremely coarse by greatly over-heating it, is cooled and subsequently re-heated (for instance, as a step in annealing), the following changes occur:

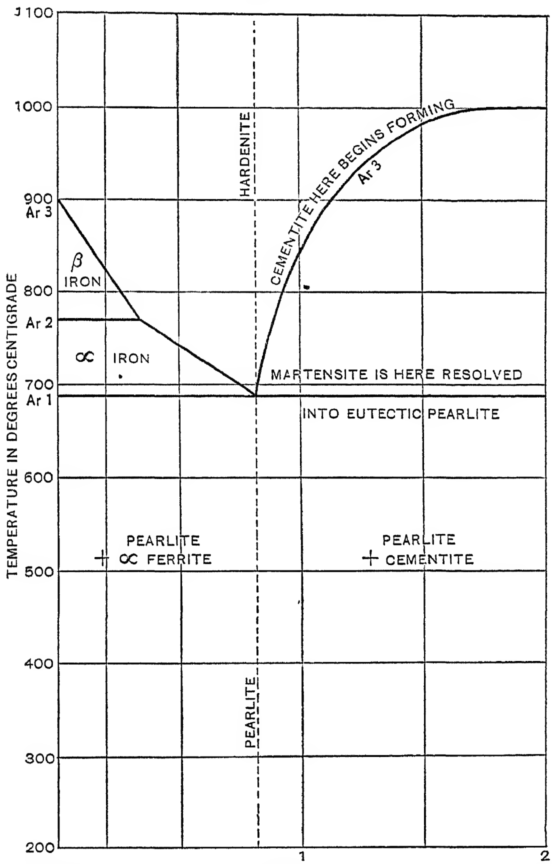
1. *Segregation below Ac_1.*—At a temperature slightly below Ac_1, cementite seems to segregate into rings, apparently because of surface tension. Mr. Göransson has furnished, so far, only slight hints as to this action.

2. *Behavior of the Net-Work of Cementite.*—If the temperature is carried above Ac_1, the cementite net-work is progressively re-absorbed by the grains of martensite which it surrounds. A part of Roberts-Austen's diagram, reproduced in Fig. 3, shows that, in the cooling of such hyper-eutectic steel from about 950° (Ar_3) to 690° (Ar_{2-1}), in which range the mass of the material is in the condition of martensite, the solvent power of this martensite for cementite progressively diminishes, so that cementite progressively separates out within the martensite, forming itself

into a net-work, the coarseness of which is proportionate, roughly speaking, to the temperature to which the steel had been previously heated, or, in other words, to what I have been in the habit of calling "T. max."

Now, the re-absorption of the net-work of cementite, which

FIG. 3.



Cooling-Curves of Hyper-Eutectic Steel, Modified from Roberts-Austen's Diagram. The abscissas refer to percentage of carbon.

Mr. Göransson has observed, is simply the converse of this. As the temperature rises from $Ac_{2\text{-}1}$ toward Ac_3 the solvent power of the martensite progressively increases; that is, the martensite is able to re-dissolve more and more of the previously-formed cementite net-work. This progressive increase

in the solvent power of the martensite for cementite, and the simultaneous increase in the ease of diffusion with rise of temperature, suffice to explain readily the progressive re-absorption and final disappearance of the net-work of cementite. Mr. Göransson's observations in this respect confirm earlier (unpublished) observations of my own.

When hyper-eutectic steel is heated above the critical range, and thus passes into the condition of martensite, and is then subsequently cooled, and thus changed back into pearlite and cementite, the net-work of the cementite is coarser, the higher the temperature to which the steel has been heated. It is an important question, whether this progressive coarsening of the cementite net-work is due to progressive change in the polarization of the martensite or in that of the cementite itself. It is true that in martensite which is free from this net-work of cementite, it has not yet been found possible to distinguish exactly this form of progressive coarsening. In my opinion, however, this is only because we have not yet learned how to detect this change in the martensite. So far as Mr. Göransson's observations go, there is nothing to show that the cause of coarsening is not a progressive change in the polarization of the cementite, corresponding to the temperature at which the cementite begins to separate out of the martensite in cooling. This temperature would be T. max., provided that T. max. does not rise above Ac_3,—as may indeed have been the case in his experiments. However, in the steel which Mr. Sauveur and I examined,* we found that this coarsening continued at temperatures far above Ac_3,—at temperatures, consequently, at which no cementite existed. In my opinion, this shows that the progressive coarsening of the grain is due to a change in the polarization of the martensite and not of the cementite, since the temperature at which the cementite would begin to form in cooling would be one and the same, viz., Ar_3, no matter whether T. max. has been only slightly, or very far, above Ac_3.

3. *The Formation of a New Net-Work of Cementite Observed by Mr. Göransson.*—When the over-heated and then cooled steel is re-heated to between Ac_{2-1} and Ac_3, for instance to 800° C., part of the cementite, which in the former cooling had become insoluble and had therefore separated out between 800° and

* See *Eng. and Min. Jour.*, vol. lx., Dec. 7, 1895, p. 537.

Ar_{2-1}, again re-dissolves and diffuses into the surrounding martensite. When the steel is now again cooled, the solvent power of the martensite for cementite again decreases; hence the cementite which had been re-absorbed is now re-expelled, and in this new expulsion forms a new net-work. It is in accordance with the views which I have just expressed that the coarseness of this new net-work of cementite increases with T. max.

4. *Blurring and Subsequent Re-Clearing of Pearlite.*—Mr. Göransson observes that if the steel be heated only slightly above Ac_{2-1}, the pearlite found in it after re-cooling is blurred. If, however, the heating be carried somewhat higher, the pearlite is again cleared. An obvious explanation suggests itself. The original pearlite was formed through slow cooling from Ar_{2-1} downward, which splits up the martensite into alternate layers of ferrite and cementite. On re-heating past Ac_{1-2}, these tend to re-combine to form martensite again; but at the relatively low temperature at which this occurs, and in the relatively rigid state of the metal, the re-combination and diffusion of the sheetlets of ferrite and cementite into each other are relatively slow. If we arrest the heating when the temperature has passed only very little above Ac_1, this diffusion is incomplete, so that traces of the former pearlite structure remain in red-hot metal. When this now cools below Ar_{2-1}, and the martensite formed by this imperfect diffusion again resolves itself into pearlite, we can hardly expect that the new pearlite will be well laminated; for such good lamination should occur only when the original mass in which the pearlite forms is approximately homogeneous. Under the conditions which we have been assuming, the structure of the old pearlite may be expected to cross that of the new. Consider two adjoining sheetlets of the original ferrite and cementite; suppose that, with the heating past Ac_1, they had diffused so far that but one-quarter of them had re-constituted martensite of the pearlite composition (viz., 0.80 per cent. carbon), but that on either side of this band there were regions of hyper-eutectic and hypo-eutectic martensite respectively. In their recombination, then, these two sheetlets will have formed at this moment a flake of martensite of very heterogeneous composition; and this heterogeneousness is quite sufficient to explain why, when the martensite again splits up into pearlite, that pearlite should be irregular, as reported by Mr. Göransson, instead of being well-laminated.

As the distance above $Ac_{1\text{-}2}$ to which the re-heating is carried is progressively increased, so should the diffusion of the ferrite and cementite, and the homogeneousness of the resultant martensite, increase; and so should the regularity of the pearlite, which, in turn, results from the re-decomposition of that martensite on again cooling, increase. Thus may the blurring and re-clearing of the pearlite be explained.

The explanation of the clouding and clearing of the pearlite can be tested in a simple way, which will probably be carried out in my laboratory. It is as follows: Heat a series of specimens of steel to temperatures varying progressively from barely above Ac_1 to a temperature high enough to bring about the clearing of the pearlite; but, instead of cooling them slowly so as to form new pearlite, quench them in water. If my explanation is correct, then those quenched from temperatures only slightly above $Ac_{2\text{-}1}$ should exhibit traces of the old pearlite structure, whereas those quenched from higher temperatures should show no such traces. Osmond has given the first indications in this direction in his masterly *Methode Générale*,* in which he figures the diffusion of the ferrite and cementite into each other in passing through the stage of sorbite.

5. Mr. Göransson's observation, that the polygons are smaller in the center than toward the outside of the specimens, agrees with older observations on fracture, and tends to bring fracture and micro-structure into harmony.†

* *Bull. Soc. d'Encouragement*, May, 1895, pp. 35–61 of extract; see preferably the reprint in the "Contribution a l'Étude des Alliages," (*Société d'Encouragement*), 1901, p. 277.

† Compare Discussion of Metcalf, *Trans. Am. Soc. Civ. Eng.*, xvi., p. 388, and the writer's *Metallurgy of Steel*, p. 176.

Gold Mining in McDuffie County, Georgia.

BY W. H. FLUKER, TATHAM, GEORGIA.

(New York and Philadelphia Meeting, February and May, 1902.)

McDUFFIE COUNTY, once a part of Columbia county, lies in the eastern part of central Georgia, about 20 miles west of the Savannah river, and bounded on the northwest by Little river. Wrightsboro, now almost forgotten, was one of the principal towns of Georgia before the Revolutionary war, and much of the land hereafter described as belonging to one of the principal gold-bearing sections of the South had been taken up by the early agricultural settlers, and was already under cultivation. Indeed, some of the present mining companies can trace their chain of title back to the original grant of King George III., made in 1771. The first discovery of gold in Georgia, however, was not made until 1823, when two English miners, who had emigrated to this country and were traveling as peddlers through this section, discovered quartz, rich in gold, on what is now known as "the 40-acre lot," and owned by the Columbia Mining Co. These men had no money to buy the lands, and not being able to stake off a claim and begin work, as is the custom in other places, they were forced to seek the aid of the native farmers. In this we are told that they were for a long time unsuccessful; the farmers and land-owners not knowing or caring anything about gold mining.

In 1826, Jeremiah Griffin, a wealthy farmer, became interested with them, and they did some prospecting and located several rich veins. Mr. Griffin soon became enthusiastic, and bought about three thousand acres of supposed gold-lands, lying along Little river. This purchase was unfortunate for the mining industry, as it effectually shut out all other prospectors, and confined entirely to Mr. Griffin and his associates the mining development of the whole region. As a consequence, the ground was never covered, and there are virgin lands in this section now, which offer to the prospector as

much hope of reward as the unexplored lands of any part of the world that I know of.

The gold-belt is about two miles wide, and extends from Hancock county on the southwest, through Warren, McDuffie and Lincoln counties in Georgia, and, crossing the Savannah river, through South and North Carolina. The country-rock is usually hydromica-schist on both walls, although some of the principal veins lie along the line of contact between the hydromica-schist and the granite and gneiss, which constitute the country-rock of the region lying NW. of the belt.

While no geologist has yet decided to what particular geological period these veins and rocks belong, it is believed that they are of entirely different and much more recent formation than those of the Dahlonega district.

The gold occurs in fissure-veins, which usually strike about N. 50° E. (the general strike of the formation), and usually dip, with the formation, about 60° NW.

They frequently continue in an almost unbroken line, with regular dip and strike, for several miles, although, of course, they vary in thickness from mere gravel seams to zones many feet wide. The material, a hard, massive quartz, occurs, not in lenses, but in shoots, which pitch to the north, and continue downward with uniform thickness as deep as any work has yet been done. The veins are separated from the country-rock by the usual few inches of gouge, and frequently show a ribbon or banded structure; it is often along the faces formed by the banding that the finest specimens of free gold are found. Whether this banding occurs or not, however, the gold is found, as a general rule, thoroughly distributed throughout the entire vein. Auriferous pyrites occurs in all the veins, particularly below water-level, and the concentrates of this character show by assay a value of from $100 to $300 per ton. The minerals which nearly always accompany the gold, and are usually regarded as indications of it, are iron and copper pyrites, galena, and pyromorphite—the latter being considered a sign of very rich ore.

The quartz is usually very clean, and the gold is coarse. The absence of slimes in the crushed product makes both amalgamation and concentration simple and easy.

Almost from the date of discovery, these mines have been

successfully and profitably worked. Exceptions there have been, of course; but they are by no means so numerous as to make the McDuffie mines different in this respect from other gold-mines of the world.

In 1833, Jeremiah Griffin purchased the rights of his associates, who had up to this time confined their work to placer-mining on a small scale. He erected a stamp-mill, the old mortars of which can now be seen, near the point on Little river where the mill was first used in 1833. They were rectangular in shape, 10 in. wide by 14 in. deep and 30 in. long. No dies were used, and there was no discharge. The stamps, of which there were three, consisted each of a square cast-iron shoe, with a square tapering neck, about 8 in. long. The neck was driven into a hole mortised in the end of a wooden stem 6 in. square and 7 ft. long, around which was placed a heavy iron band, to prevent splitting. The cam-shaft was a solid piece of wood 26 in. in diameter, with blocks, which served as cams, mortised into it. These, in revolving, came in contact with other blocks, serving as tappets, which were fastened to the wooden stem by means of iron bands and wooden pegs or dowel-pins. The mill was driven by an under-shot water-wheel, the shaft of which was a continuation of the cam-shaft. The mortars described above were soon replaced by wooden mortars provided with a discharge and screen, similar to those used at the present time, and having a single cast-iron die, which extended the entire length of the mortar. With such a mill, which was probably the first stamp-mill erected in America, Jeremiah Griffin, in the year 1837, cleared $80,000.00. The ore that he milled was nearly all taken from what is now called the Columbia vein on "the 40-acre lot,"—a vein which is still profitably worked.

In 1842, Mr. Griffin, still actively engaged in mining, was accidentally killed, and left a large fortune to his numerous heirs, who continued to work the mine until 1851, when it was sold to the Columbia Mining Company, which worked it with great success until the beginning of the Civil War, which put an end to this and all like industries in the South. The men, and such of the machinery as could be used, were required in the service of the Confederate Government, and the entire equipment was confiscated and moved away during the war.

At the close of the war, the South was left in an impoverished and helpless condition. In the preceding period, slaves belonging to the various mining companies had been worked in the mines. After the war, these slaves were free; and even if the money and machinery for reopening the mines could have been obtained, there was no labor. As a result of these conditions, most of these mines have until recently been practically abandoned. A few, however, have been worked continuously in spite of all difficulties.

The Parks mine was owned and operated successfully by Col. J. Belknap Smith until his death, in 1888, after which the work was continued without interruption by his widow, under whose personal management the business was profitably conducted until 1899, when she leased it to a company of western miners. The principal work done on this property by her was in sinking the Parks shaft to the depth of 150 ft., and running drifts to a considerable distance in each direction, along the vein. This vein lies northwest of the center of the belt, strikes almost at right angles to the general strike of the formation, and is nearly vertical. It varies in thickness from 2 to 11 ft., and in value from $10 to $200 per ton. The average free-gold value of ore mined for three years in this vein was $34.60 per ton; and assays show that fully half the total value of the ore was contained in the sulphides, which for about 40 years have been allowed to flow into the river below the mill. Little or no improved machinery was employed by Mrs. Smith. The ore had been so rich in free gold, and had been so easily treated, that it never seemed to her to be necessary to go to the trouble and expense of concentration; and she made no attempt to save anything but the free gold.

This property, which contains 105 acres, is traversed by numerous other veins. Several of them have been worked with profit to a depth of from 60 to 120 ft. Below this depth, the values are largely contained in the sulphides, and it has not been found profitable to work the lower ground for free gold only.

James Frank, on what is now known as the National mine, was also very successful, developing several veins to the depth of from 50 to 75 ft., and finding free-gold values, varying from $4 to $20 per ton. Mr. Frank made no attempt to concentrate

his ore; and when he reached the point below water-level where the sulphides were no longer decomposed and the values could not be obtained by amalgamation, he, like all the rest, concluded that the ore was worthless, and abandoned that working to begin again on some other vein. In 1893, Mr. Frank sold his mine to Gen. Joseph H. Porter of New York, who did considerable development-work on the property, sinking the Egypt and Brock shafts to the depth of 110 ft. The ore was found satisfactory, and he began the erection of a modern mill, but died before its completion. In 1897 the property was sold to the Four Oaks Mining Co., and in 1899 to the National Mining Co. of Chicago. This company now has a modern 20-stamp mill practically complete, in which one Wilfley and one Bartlett concentrator are used, and are said to give excellent results. The company has sunk the Brock shaft to about 140 ft., and drifted about 75 ft. along the vein. The vein at this level is 4 ft. thick; and an average sample assayed $21.40 per ton.

The Tatham mine, though not now worked, has several years of profitable operation to its credit; and it is understood that preparations are now making to reopen the Slate shaft, which was worked by Tatham Brothers of Philadelphia for a number of years, and has the reputation of having supplied ore that yielded $2000 per ton by amalgamation. There is a 10-stamp mill, with Wilfley concentrators, on this property.

The Landers mine is a new discovery and has only been worked a few months. Two veins varying from 5 in. to 18 in. in thickness have been located on the property, and are said to assay from $20 to $30 per ton. No machinery has been put on this property and none of the ore has been milled.

The Woodall mine is now idle on account of litigation; but, when shut down, it was yielding ore said to be worth $50 per ton, from a vein averaging 16 in. in thickness, and at a depth of 100 ft.

The 40-acre lot of the Columbia mine has been, both before and since the Civil War, the most extensively worked property in McDuffie county. As the place of the first discovery of gold in Georgia, it has naturally been a center of operations; and the success of Jeremiah Griffin, John and Lewis Parks, Henry Leitner, J. Belknap Smith and others bears witness to the rich-

ness and continuity of the veins. Although 200 ft. is the greatest depth reached by any of these miners before the war, records kept by Col. Smith show that more than $2,000,000 has been extracted from ore mined on this property. The 40-acre lot is almost square, and, like the Parks, lies slightly NW. of the center of the belt. It is traversed by what, at the depth thus far attained, seems to be two systems of veins, the Columbia and the Bell. The Bell is farthest north, and is now worked at the depth of 140 ft. by the Columbia Mining Co. The ore is found to be valuable both in free gold and in sulphides. Ore from this vein is now yielding in free gold about $17 per ton, which is about half the assay-value. The foot-wall of the vein is hydro-mica slate. The hanging-wall is gneiss, and is separated from the quartz by from 1 to 3 in. of gouge, while the slate in the foot-wall seems almost blended with the quartz, and is impregnated with cubes of pyrite, which give the slate a gold-value of about $4 per ton for a distance of 10 ft. from the vein, which is as far as prospecting has gone. This vein follows the general strike of the country-rock, about N. 50° E., and dips 60° NW. It has been drifted on for 565 ft., showing a continuous vein of almost uniform values.

The Columbia vein lies about 600 ft. S. of the Bell, and is the larger of the two. It is nearly parallel to the Bell, but dips 45° NW. Both walls are hydro-mica schist, and are separated from the quartz by the usual thickness of gouge. The foot-wall is regular and unbroken, while numerous spurs branch out from the hanging-wall towards the Bell. The vein varies in thickness from 2 to 20 ft., and in value from $2 to $100 per ton. The deepest work has been done by the present owners in an incline shaft, now 325 ft. deep, at the bottom of which the vein is 5 ft. thick and assays $32.20 per ton. Drifts have been run on the vein at several points. At the 175-ft. level the drift is 720 ft. long, and shows a continuous ore-body. From other cuts and shafts on the surface along the line of strike, this vein is known to continue for a long distance on each side of the shaft. Thus far, the work of the Columbia Mining Co., which has been operating the mine since June 1, 1899, has been done for the purpose of developing the property. Numerous shafts have been sunk, and pay-ore has been found in most of them. The work has been done in a substan-

tial and permanent manner, and it is proposed to extend the present incline shaft to a depth of 1000 ft. The company has erected on its property a 10-stamp mill with Wilfley concentrators, and has run constantly for the past two years on ore that has averaged $9.20 per ton in free gold. The concentrates have not yet been turned into money, but are stored at the mine, and will probably be shipped to a smelter for treatment. One lot of these concentrates, shipped to the Southern smelter at Atlanta, Ga., netted about $82 per ton.

There are numerous other veins and prospects, not only in McDuffie, but also in Warren and Lincoln counties, some of which are worked profitably at this time, but nearly always on a limited scale. Inexperience and lack of capital are the two drawbacks to the prosperity of mining in this section. When these shall have been overcome, McDuffie county will take its place among the great gold-producing districts of the United States.

The Direct Cyaniding of Wet-Crushed Ores in New Zealand.

BY HAMILTON WINGATE, B.SC., AUCKLAND, N. Z.

(New Haven Meeting, October, 1902.)

UNTIL recently, the universal practice in New Zealand was dry-crushing and direct cyaniding. With ores containing no mineral sulphides, and little or no coarse gold, this method, in spite of its many disadvantages, gave excellent results, and was by far the best one available, pending the solution of the slimes-problem. But the situation has now been changed. The successful treatment of the slimes, enabling the mines not only to do away with dry-crushing, but also to deal with the mineralized ores of the lower levels, which are, for obvious reasons, quite unsuited to that method of treatment, has made wet-crushing universal; and this may be taken as satisfactory proof of its superiority over the former practice.

In the lack of accurate information from plants operating successfully, particulars of experimental trials carried out on a working-scale at the Waitekauri Extended mine, Maratoto,

N. Z., while the writer was in charge of the cyanide-works, may be interesting to members of the Institute.

At this mine the usual method of kiln-drying, dry-crushing and subsequent cyaniding, for which the plant had been specially designed, was the system in vogue; but while the extraction was high, the working-costs were heavy; and the treatment, though applicable to the oxidized surface-ores, was not suited to those of deeper levels. The ore being, moreover, of low grade, a change of treatment became imperative. The experiments here described were consequently made after such alterations in the plant as were necessary and practicable.

The choice of a satisfactory process depended on the successful treatment of the slimes, which formed a large proportion of the crushed ore, and, as was subsequently discovered, also contained the larger part of the total value. The use of lime, successfully introduced on the Rand by Mr. Williams, was found to satisfy this condition; and the results, in view of the somewhat refractory nature of the ore, are interesting.

Nature of the Ore.—The ore is an extremely hard, flinty, bluish quartz, intermixed with finely-divided iron pyrites, the gold-contents being pretty uniformly distributed in an excessively fine state of division, and silver being present as sulphide. Analysis showed the quartz to contain 5 per cent. of iron pyrites, with traces of calcium and manganese, the average value being from 6 to 8 dwt. of gold and about 1 oz. 15 dwt. of silver per ton of 2240 lbs. The high cost for shoes and dies, as shown below in the table of working-expenses, will convey some idea of the very hard nature of the ore, which, owing to the fine state of division of the gold, had to be crushed through a 40-mesh screen in order to secure an adequate extraction. A prolonged amalgamation-test on a large amount of ore gave a very small percentage of the total bullion-contents. This being the case, and the ore carrying no visible gold, all attempts at amalgamation were discarded.

The association of the gold- and silver-contents with the mineral sulphides of the ore is shown by the two following experiments:

A. Blanketings weighing 72 lbs., obtained from 7.5 tons of ore, and crushed through a 40-mesh screen, assayed as follows per ton:

	Oz.	Dwt.	Gr.
Gold, ...	1	11	0
Silver, ...	3	8	14

B. Clean mineral, obtained from the concentration of a large tonnage of slimes in the main slimes-launder, assayed as follows per ton:

	Oz.	Dwt.	Gr.
Gold, ...	4	18	0
Silver, ...	10	12	8

This raised the question whether concentration would be necessary; but after experiments, both in the laboratory and on a working-scale, it was decided to classify the pulp into two classes only, namely, sands and slimes.

The largest proportion of the mineral sulphides in the ore crushed to slimes. This accounts for the higher value of the bullion-contents of the slimes as compared with the sands.

After cyanide treatment of the sands, average samples of clean mineral, obtained by concentration from the residues, assayed as follows per ton:

	Oz.	Dwt.	Gr.
Gold, ...	0	4	21
Silver, ...	1	6	2

This shows a high extraction from the contained mineral sulphides. In experimenting on the mineral concentrates in the laboratory, it was not found possible, even by using a solution of higher strength, to get the residues below 4 dwt. per ton in gold without first crushing them finer.

With reference to the mineral-contents of the slimes, one of the initial difficulties was the tendency of the mineral sulphides to separate out during agitation and settle on the bottom of the vat. These assayed as follows per ton:

Before treatment:

	Oz.	Dwt.	Gr.
Gold, ...	1	7	18
Silver, ...	5	9	10

After treatment:

	Oz.	Dwt.	Gr.
Gold, ...	0	9	18
Silver, ...	2	17	4

Experiments showed that the poor extraction was due to want of proper agitation. It is essential that the agitators be

so constructed that when in motion they will sweep the bottom of the vat perfectly clean. The agitator adopted consists of a central revolving shaft, which can be raised or lowered as required, and carries two parallel fixed wooden arms, set 3 ft. apart, the lower arm reaching within 9 in. of the bottom of the vat. Holes are bored through the arms at regular intervals of 6 in., and wire-rope (some old ¾-in. aërial cable being used), cut into 5.5-ft. lengths, was passed through them and keyed into position, the ends next the bottom of the vat being teased out so as to act as a sweeper.

This was an effective agitator. The assays of the mineralized portion of the slime-residues, in two successive charges, were as follows per ton:

Charge No. 1:

	Oz.	Dwt.	Gr.
Gold, ...	0	2	10
Silver, ...	1	6	2

Charge No. 2:

	Oz.	Dwt.	Gr.
Gold, ...	0	2	0
Silver, ...	1	2	10

These results show a good extraction from the contained sulphides.

General Description of the Treatment.—The mortar-boxes, which had the double discharge for dry-crushing, were altered to single discharge for wet-crushing; but even after this change were obviously unsuited to the work. This fact, no doubt, increased the percentage of slimes; but it was found in actual practice much easier to get a good extraction from the slimes than from the sands. A number of sizing-tests on the sand-residues showed that the greater part of the gold which they retained was in finely-divided form in the coarser quartz particles.

The ore was crushed through a 40-mesh screen. The classification of 656 tons crushed gave 355 tons, or 54.11 per cent., of sand, and 301 tons, or 45.89 per cent., of slimes. A sizing-test of the sands taken during this period is shown in the table on page 129.

It thus appears that, taking the sands and slimes together, 70 per cent. of the pulp, on an average, was crushed fine enough to pass through the 80-mesh sieve, this being the fine-

Mesh.		Per Cent.
Through.	On.	
40	50	6.9
50	60	9.4
60	70	27.5
70	80	8.7
80	90	29.4
90	100	1.9
100	....	15.0
	Loss......	1.2
		100.0

ness, as determined by experiment, requisite for a good extraction.

The crushed pulp passed direct from the mill to a *spitzkasten*, 5 ft. square at the top, coming to a point 5 ft. deep, and provided with a 2.5-in. cock at the apex to regulate the discharge of the sand-pulp. A rose, connected with a 1.5-in. high-pressure pipe, passing down the center of the *spitzkasten*, reaches to within a few inches of the bottom. The inclined sides only of the rose are perforated. When the *spitzkasten* is at work, this throws an upward spray of water under pressure.

The success of the treatment depends largely on good classification, since any slimes carried over with the sands are apt to be lost in the overflow from the sand-vats; while, on the other hand, any fine sands present in the slimes will cause a portion of the slime-pulp to set hard at the bottom of the vat, in a mass too tough to be affected by the agitator. There is in this case a consequent loss in the ultimate cyaniding through non-treatment. It was only on the addition of the rose to the *spitzkasten* that a satisfactory separation was obtained.

The resulting products were treated quite separately. The discharge from the *spitzkasten* passed to a sand-vat, where it was discharged through a Butters distributor; and the overflow of the *spitzkasten*, constituting the corresponding slime-charge, passed to one of the agitator-vats.

Treatment of the Sands.

The average charge was 30 tons, the vats being circular, 20 ft. in diameter and 4 ft. deep. The sands were treated in the

ordinary way, after a preliminary alkaline wash according to requirements, followed by a wash from the "No. 2 weak" sump, in order to reduce the initial consumption of cyanide on the first contact of the strong solution with the ore. An 0.5-per-cent. solution of cyanide for the dissolution of the gold- and silver-contents was followed by the usual washes from the strong and the weak sumps, with a final water-wash to displace the cyanide-solution. The sands being a perfectly clean, uniformly leachable product, quite free from slimes, presented no special difficulties in treatment.

Treatment of the Slimes.

The slime-vats were circular, 22 ft. in diameter and 7 ft. deep, and the average charge (corresponding to a 30-ton charge of sands) was 25 tons of slimes per vat. The overflow from the *spitzkasten* being carefully run in at one end of the vat, the clear liquor was allowed to flow away at the other; and when the vat had been charged, the slimes were allowed to settle, and the water was drained off by means of an inside siphon-pipe, leaving a pulp which contained, after draining, from 42 to 58 per cent. of dry slimes. The agitator was now started, being at the same time gradually lowered. The value of the charge was ascertained by means of dip-samples, taken during agitation, which we found to give most accurately the value of the total bullion-contents. Lime was now added in sufficient quantity to coagulate the slimes (14 lbs. per ton of dry slimes being the average amount required), and the charge was agitated for an hour in order to neutralize the effect of the free acid and other "cyanicides" present in the ore.

In order to economize cyanide, and prevent the volume of the sump-solutions from becoming unmanageable (our sump-accommodation, during these experiments, being limited), the amount of dry slimes and of water in the pulp was carefully estimated in the sample of the slimes-charge, and the required amount of cyanide, dissolved in 5 tons of No. 1 "strong sump," was added, in order to bring up the total solution present in the charge to 0.16 per cent. of cyanide. This strength of solution, found in actual practice necessary for the effective solution of the gold and silver, was higher than the preliminary laboratory-experiments had indicated. These, however, were

not made under exactly similar conditions. The charge of slimes-pulp, which occupied a depth of from 3 ft. to 4 ft. in the vat, was now agitated at the rate of 40 revolutions per minute for 3 hours (the time necessary to obtain a satisfactory solution of the bullion-contents); solution from No. 1 strong slimes-sump was then pumped on, and agitation was continued until the slimes-charge was complete, the pulp now occupying a total depth of 6.5 ft. The agitator was now raised, and the slimes allowed to settle, after which decantation began.

The arrangement for drawing off the cyanide-liquors consisted of a 2-in. wired rubber hose, fixed inside the vat, and connected at the bottom and close to the side of the vat with the solution-pipe to the extractor-boxes. The end of the hose is held firmly in an iron collar, to which is attached an arm of $\frac{1}{2}$-in. square iron. This arm passes through a guide, which can be moved freely along a $1\frac{1}{2}$ by $\frac{3}{8}$-in. iron-bar, 3 ft. long, which is bolted to the inside edge of the top of the vat. A thumb-screw through the guide holds the arm in position; and, as the hose is lowered, the guide can be moved along the fixed iron-bar and the arm securely clamped. When not in use, the arm is raised and clamped, and the hose, being drawn up close to the side of the vat, is clear of the agitator.

Since there was no intermediate storage-tank, and the solutions had to be drawn off direct from the vats to the extractor-boxes, this was found to be the safest arrangement. Care was taken not to set the mouth of the hose too close to the level of the slimes, as on draining off, the pressure of the top solution being removed, they rise. Automatic floats were found unsatisfactory, as they were both difficult to adjust and required a considerable amount of watching; while, with the arrangement described, once the hose-pipe is properly set, it only requires lowering occasionally, and there is no risk that slimes will pass along with the liquors into the extractor-boxes. After drawing off the first wash, agitation with sump-solutions, followed by decantation, was continued, until a satisfactory extraction was obtained. Additional lime was added, if required; but the preliminary coagulation was usually sufficient.

From four to eight washes were required, according to the size of the charge and the nature of the slimes-pulp, which was at some times more bulky than at others. The total weight of

the washes required was from three to four times that of dry slimes present in the charge.

Each wash was in every case passed through the extractor-boxes before being returned to the slimes-vats. The precipitation was satisfactory even in the most dilute solutions. The rate of flow through the extractors was regulated to 2 tons of solution per hour per cub. ft. of zinc-shavings.

The following is a summary of the results obtained during the experiments, on a working-scale, upon 1440 tons of different classes of ore, taken from the mineralized portion of the reef at the lower levels.

Summary of Working Results.

Report No. 1.

During the period from August 27 to October 4, 1900, quartz from the north end of the Low level only was crushed, the ore being, as already described, extremely hard, and containing 5 per cent. of finely-divided iron pyrites. The amount of ore crushed was 656.1 tons.

Classification: The separation by the *spitzkasten* was as follows:

355 tons passed to the sands-vats = 54.11 per cent.
301.1 " " slimes- " = 45.89 "

656.1 tons.

The total gold was divided as follows: in the sands, 46.9 per cent.; in the slimes, 53.1 per cent.

Of the total silver, 41.28 per cent. was in the sands and 58.72 per cent. in the slimes.

Extraction.—The following tables show the extraction:

Gold.

	Tons of 2240 lbs.	Total Gold.			Gold Per Ton.			Gold in Residues.			Gold Per Ton.			Percentage Extraction.
		Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	
Sands........	355	107	9	21	......	6	1	25	8	13	......	1	10	76.55
Slimes.......	301.1	121	13	23	......	8	2	17	1	18	......	1	3	86.08
Total.........	656.1	229	3	20	.....	6	23	42	10	7	......	1	7	81.43

Silver.

	Tons of 2240 lbs.	Total Silver.			Silver Per Ton			Silver in Residues.			Silver Per Ton.			Percentage Extraction.
		Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	
Sands... ..	355	477	12	8	1	6	21	262	3	20	.....	14	18	45 11
Slimes.......	301.1	679	3	22	2	5	3	375	2	8	1	4	22	44.78
Total...... ...	656 1	1156	16	6	1	15	6	637	6	4		19	19	45.03

Working-Costs.—The working-costs for milling and cyaniding are included in the cost-sheet for the total 1440 tons treated.

Report No. 2.

During the period from October 4 to November 22, 1900, two different classes of ore were crushed, namely:

I. 467.9 tons from the north end of the Low level, the nature of the ore being similar to that dealt with in the last report, and having an average value of £1 10*s.* 10*d.* per ton.

Classification :

245 tons passed to the sands-vats = 52.34 per cent.
222.9 " " slimes- " = 47.66 "

II. 315.9 tons from the south end of the Low level, the nature of the ore being much softer, more mineralized, and showing a greater tendency to crush to slimes, and having an average value of £2 3*s.* 9*d.* per ton.

Classification :

148 tons passed to the sands-vats = 46.86 per cent.
167.9 " " slimes- " = 53.14 "

The classification for the total 783.8 tons of ore crushed was as follows:

393 tons passed to the sands-vats = 50.26 per cent.
390.8 " " slimes- " = 49.74 "

783.8 tons.

Of the total gold, 46.9 per cent. was in the sands and 53.1 per cent. in the slimes.

Of the total silver, 38.8 per cent. was in the sands and 61.2 per cent. in the slimes.

Extraction.—The following tables show the extraction:

Gold.

	Tons of 2240 lbs.	Total Gold.			Gold Per Ton.			Gold in Residues.			Gold Per Ton.			Percentage Extraction.
		Oz.	Dwt.	Gr.	Oz.	Dwt	Gr.	Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	
Sands	393	135	9	14	......	6	21	33	19	5	......	1	17	75.1
Slimes.......	390.8	153	17	3	......	7	17	29	6	23	......	1	12	80.5
Total.........	783 8	289	6	17	..	7	9	63	6	4	......	1	14	78.5

Silver.

	Tons of 2240 lbs.	Total Silver.			Silver Per Ton.			Silver in Residues.			Silver Per Ton.			Percentage Extraction.
		Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	Oz.	Dwt.	Gr.	Oz.	Dwt	Gr.	
Sands..	393	526	7	9	1	6	18	291	1	17	......	14	19	44.7
Slimes.......	390.8	831	19	15	2	2	13	515	18	3	1	6	9	38.0
Total.........	783.8	1358	7	0	1	14	15	806	19	20	1	0	14	41.2

It will be noticed that the extraction during this period was lower than that shown in Report No. 1. In the case of the sands, this was found to be due to the retention of a larger proportion of the gold in the coarser quartz particles, owing to the richer nature of the ore from the south end. In the case of the slimes, the unexpectedly increased quantity to be dealt with, and the more highly mineralized nature of the ore, made this product more difficult to treat. The lower extraction of silver, which is intimately associated with the contained mineral sulphides, as compared with the sands-extraction, was due to imperfect agitation, owing to the increased amount of slimes produced from the south-end ore, which contained a greater proportion of associated mineral sulphides.

The crushed ore was sampled before entering the *spitzkasten*, as a check against the sands- and slimes-samples. All the sands- and headings-samples were ground in a Park-Lacy fine crusher to an impalpable powder before assay. The final clean-up showed the actual bullion yield to be about 3 per cent. lower than that indicated by assay.

Working-Costs.—The working-costs for both periods under review, during which a total of 1440 tons of ore were treated, are embodied in the following table. Water-power is in use

at this mill, but owing to a shortage, due to dry weather, the item for wages is higher than would otherwise have been the case; because, during a part of the time, it was possible to run only 10 stamps out of the total number of 20 which had been altered for wet-crushing.

Cost of Treatment of 1440 Tons of Ore.	s.	d
Cyanide, 2.7 lbs. per ton	3	4½
Zinc, .75 " " "	0	4
Caustic soda, .75 " " "	0	1¾
Lime, 7 " " "	0	2½
Milling and cyaniding wages	2	5
Filter cloths	0	0¼
Screens	0	0½
Shoes and dies	0	6
Oils	0	1½
Assaying and melting	0	7
Management	0	7½
Sundries, including royalty	0	3
Total cost per ton of 2240 lbs.	8	7½

The necessity of using stronger solutions, owing to the nature of the ore, and in order to obtain an adequate extraction of the silver (which is an important part of the total bullion value), makes the consumption of cyanide on these ores a good deal higher than the general average.

Conclusions.

In view of the foregoing results, it is doubtful if the higher extraction which could be obtained by concentrating out and treating separately the mineral sulphides from both sands and slimes would compensate for the extra working-costs which such a treatment would involve—to say nothing of the initial expenditure which would be necessary. Otherwise, this would seem at first sight to be the ideal method of treating such an ore. Several of the mills here crush with a cyanide-solution of about 0.1 per cent., thus obtaining a rapid solution of the bullion-contents during crushing, sometimes amounting to as much as 60 per cent. of the total value of the ore; but owing to the difficulty of preventing a large consumption of cyanide when the ore is mineralized, this method of treatment was not tried in the case here discussed.

Notes on the Treatment of Zinc-Precipitate Obtained in Cyaniding New Zealand Ore.

BY HAMILTON WINGATE, B.SC., AUCKLAND, N. Z.

(New Haven Meeting, October, 1902.)

In view of the fact that the fineness of the resultant bullion varies with the particular treatment to which the zinc-precipitate is subjected, and since there are considerable losses attributed to both methods, the following notes on the results obtained at the Waitekauri Extended mine, Maratoto, N. Z., may be of interest.

The ordinary method of roasting the vacuum-dried precipitate was adopted instead of the treatment with sulphuric acid, the necessary facilities for the latter method not being available. Moreover, provided the ordinary method is carried out with the necessary care, it is questionable if it is not the most satisfactory where large quantities of precipitate have to be handled, and where (as is generally the case in this district) a considerable amount of silver is present.

All the precipitate was first washed through a 40-mesh sieve. If it was necessary to recover the bullion at once from the accumulated short zinc, it was oxidized and melted separately; but, as a general rule, being heavily charged with bullion, it was placed on the bottom of the trays at the top end of the extractor-boxes, where it acted as an excellent precipitant, the bullion being recovered at the next clean-up.

After drying on a filter with the aid of a vacuum-pump, the precipitate was weighed and removed to the oxidizing furnace, which is similar to that generally in use in New Zealand, consisting essentially of an ordinary square tray of cast-iron, with 6-in. sides, built over a brick furnace. Wood is used as fuel. The tray is hooded over with sheet-iron, fitted with a sliding-door, and the fumes pass through a flue at the top into a dust-chamber, then into the open air.

Oxidation of the Precipitate.—The oxidation was conducted first at a low temperature, which was gradually raised, until

finally the iron tray was at a very dull-red heat, the precipitate being kept broken up with a suitable rake, and great care being exercised to avoid loss by dusting, especially as the last stage was reached. After cooling, the precipitate was carefully weighed, the time occupied in oxidizing being from two to four hours.

Melting of the Oxidized Precipitate.—The oxidized precipitate was fluxed as follows: 100 parts of oxidized precipitate; 50 parts of anhydrous borax; 15 parts of anhydrous sodic carbonate; and, after mixing, carefully charged into a No. 50 plumbago crucible, and melted at a moderate heat, the pot being kept carefully covered during fusion, and recharged in each case before fusion was quite complete. When three-quarters full, the temperature was raised, the slag, now thoroughly liquid, was ladled off into moulds, and the crucible recharged as before, until about two-thirds full of molten bullion.

The bullion was now poured into moulds, each bar being again melted in a crucible of smaller size, and skimmed, if necessary, before pouring. After washing, the bars were then sampled and weighed.

The following table gives the particulars of eight consecutive clean-ups, and the fineness of bullion obtained:

No. of Melt.	Weight of Vacm. Dried Precipitate.	Weight of Oxidized Precipitate.	Per Cent. Yield of Bullion from Oxidized Precipitate.	Total Weight of Bullion Obtained.	Fine Gold Contained in Bullion.	Fine Silver Contained in Bullion	Fineness of Bullion Per 1000 Parts in Gold and Silver.
	Lbs. Avoir.	Lbs. Avoir.		Oz. Troy.	Oz. Troy.	Oz. Troy.	
1	112	56	61.9	505.8	115.86	343.94	909.0
2	65	33.75	53.0	261.1	57.44	181.46	914.5
3	95	55	72.2	581.75	110.37	433.23	936.1
4	130	76.5	55.7	622.05	130.75	464.28	956.5
5	88	53	52.1	403.35	84.82	304.12	964.2
6	150	86.5	45.1	569.25	129.23	417.82	961.0
7	71	43.5	58.8	393.85	92.84	278.77	943.5
8	122	62	41.3	373.55	86.29	263.35	935.9
Total.	833	466.25	54.8	3710.70	807.60	2686.97	941.7

NOTE.—In the case of Nos. 1, 3, 5 and 7 only the top partitions of the extractor-boxes, containing the most of the precipitate, were cleaned out, whilst in the case of Nos. 2, 4, 6 and 8 a complete clean-up of the extractor-boxes was made. The

bullion was recovered from ore all of which had been wet-crushed.

The fineness of the bullion obtained was mainly due to the passing of the precipitate through the 40-mesh sieve, thus eliminating the "short zinc." It is impossible to oxidize such zinc, scattered throughout a mass of bulky precipitate. Its presence causes both mechanical losses and losses through volatilization, and it is most important that it be either eliminated or oxidized, if subsequent losses in melting are to be avoided.

Sampling of the Bars.—The bars so obtained were of very uniform composition, and the drillings from a hole right through the bar gave very accurately its actual value. The base metals present were zinc, together with lead, iron and copper, in small quantities, the latter being derived most probably from the fulminate-caps used in the mine, as no trace could be detected of its presence in the ore.

Slags, Etc.—These were crushed in the mill, giving a return equal to 1½ per cent. of the total bullion recovered, the tailings, as bagged for shipment to the smelter, being worth, according to careful sampling, £25 per ton. The sweepings from the dust-chamber and flue resulted in the recovery of bullion of a total value of £9 after the oxidizing of some £6000 worth of precipitate, showing the loss from this source to have been small.

Notes on the Cost of Hydraulic Mining in California.

BY W. E. THORNE, GEORGETOWN, CAL.

(New York and Philadelphia Meeting, February and May, 1902.)

In his paper on the hydraulic mining of a low-grade gravel in California,* Mr. W. H. Radford expresses the hope that other members of the Institute will contribute, for the benefit of all, their experience in similar lines. In these notes I shall describe the conditions and results of the operation of the Gold Bug Mining Co., of Cleveland, O., at Georgetown, Eldorado county, Cal.

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* *Trans.*, xxxi., 617.

This district drains into the American and Sacramento rivers, and is thus subject to the U. S. Débris Commission, which requires from every hydraulic mine the building of a dam to impound the tailings.

The property of the company lies in a narrow cañon, $1\frac{1}{4}$ m. long, with an average width of 200 ft., and a maximum depth, at the upper end, of 23, and a minimum depth, at the lower end, of 7 ft. This difference of depth is due to the existence, at the upper end, of "seam-diggings," which have been depositing their tailings in the cañon for the past 50 years. These tailings have been carried down and scattered over our ground by every freshet, until, at the present time, they constitute about 60 per cent. of our gravel.

The ground is worked through bed-rock sluices, mostly 8 ft. wide on the bottom, and laid in a cut having at the lower end the maximum depth of 25, and at the upper end the minimum depth of 4.5 ft. At the lower end, each 12-ft. box has a fall of 4 in.; at the upper end, the fall is but 1 in. per 12-ft. box. There is 1300 ft. of the 8-ft. sluice and 200 ft. of 4-ft. sluice, making a total of 1500 ft. of bed-rock sluice.

The mud-sills at the head of each box, 6 by 6 in. in size, are held in place by a drift-pin of $\frac{7}{8}$ in. round iron, driven into bed-rock horizontally, at each end. The intermediate mud-sills are 4 by 6 in. pieces, placed on edge, and held in the same way as the end-sills. The bottom is of 2 by 12 in. stuff, with a center-board 1.5 by 18 in., placed on edge, so that at low water one side will carry the water while the other is being cleaned up.

The sides, 36 in. high, are made up of two 1.5 by 18 in. boards on each side, and have a batter of 1 in. in 6 in., making the sluice 1 ft. wider at top than at bottom. The sluices are paved with 6 in. blocks, set on end.

This construction cost from $4 to $150 per linear foot. Hand-drilling in hard diorite, which constituted a part of the formation at the lower end, was the cause of the maximum cost. Most of the cut is through Mariposa and Calaveras slates.

Our grade became so light (1 in. to 12 ft.) at the upper end that we had to depend on the maximum flow of the creek (about 3000 miners' inches, which continues for only about 15 days in the year) for our sluice-head. Our head for the Giant

we obtained, at a cost of 0.5 cent per hour per miners' inch, from a ditch owned by another company. We used, through a 3-in. nozzle, 200 miners' inches, under a head of 180 ft. Our average of material moved was 43.5 cub. yd. per hour—a very low duty, due to our working up-stream.

The value saved per yard, and other data of that kind, I am not at liberty to give. Such particulars, belonging to the private business of a given company, and involving, as a factor, the value of its mining ground, has really little or no technical value. It may satisfy curiosity, but it does not benefit science or practice. The percentage of recovery or loss, calculated upon trustworthy sample-assays of the crude material, would be, indeed, valuable as a guide to possible improvements in apparatus or operation. But such a calculation is not practicable in hydraulic mining. I give, therefore, all that I have which seems likely to be useful, namely, a statement of the working-costs, so classified as to permit comparison, item by item, with those of similar enterprises.

Working-Costs per Cubic Yard of Material Hydraulically Moved.

Water,	$0.030
Labor,	0.015
Débris dams,*	0.030
Moving of pipe, etc.,	0.005
"Crevicing" and cleaning bed-rock,	0.006
Taxes, salaries, etc.,†	0.007
Blacksmithing,	0.003
Lumber,	0.030
Labor on sluices,	0.040
Powder, fuse, etc.,	0.017
Total,	$0.183

Our supplies, delivered at the mine, cost as follows: Lumber (rough), $14 to $16 per M.; powder, 12 to 13 cts. per lb. in ton-lots; fuse (triple tape), by the case, 50 to 55 cts. per 100; caps (No. xxx.), 60 to 65 cts. per 100; round iron ($\frac{7}{8}$ in. diam.), 3.5 cts. per lb.; nails (cut and wire, by the keg), 3.5

* This item represents the total cost of such work, divided by the total capacity in tons of the reservoirs thus created.

† This item is exceptionally large, because of the short season of 15 days, upon which the calculation is based, and the consequently small amount (7500 cu. yds.) of material moved. The other items are more nearly a fair average; though, of course, the short season of operation had in many ways an indirectly unfavorable effect on costs.

to 4.5 cts. per lb. The wages of miners were $2.50 per day of 10 hours.

The method above described was in operation when I took charge of the mine; and, to my request for permission to substitute a dredge or hydraulic elevator, it was replied that as the existing system had been installed under the advice of experienced placer-miners, I must give it a trial. The result, as the statement of costs might lead an expert to expect, was not economically satisfactory; and we are now installing a hydraulic elevator, of which I hope to have something to say in the near future.

Two under-currents were tried. No. 1 was placed about 700 ft. below the lower end of the bed-rock sluice. (It should have been at the sluice and connected with it.) It cost about $1500, and saved about enough gold to pay the taxes and interest on that investment, together with the cost of cleaning it up. No. 2, placed 1500 ft. below the lower end of the bed-rock sluice, cost $1700, and has never caught enough gold to pay the cost of cleaning.

I have given the foregoing statement, showing our maximum costs, as a companion-piece to Mr. Radford's notes, in order that those who contemplate investments in hydraulic mining may not be led to believe that all enterprises of that kind can be operated as cheaply as the one of which he writes.

In the instance here described the company was misled, by reports of exceptional cases, into the belief that this property, like others of which they had read, could be handled with Giants and ground-sluices at very low cost. As the foregoing statement shows, the costs turned out, on the contrary, to be very high.

Mr. Radford's opinion that, "under fairly favorable conditions gravel of quite low grade can be worked at a profit," calls for a further definition of what would constitute fairly favorable conditions." According to my knowledge of hydraulic mining in California, one of these conditions must necessarily be that the property must lie outside of the drainage-basin of the Sacramento; for, within that area, the cost of the required impounding dams *alone* would almost equal the value of the gravel he describes.

Most men write of their successes only. Why not, once in a while, tell of a failure, as I have here done?

The Calculation of the Weight of Castings with the Aid of the Planimeter.

BY C. M. SCHWERIN, E.M., CHICAGO, ILL.

(New York and Philadelphia Meeting, February and May, 1902.)

THE object of this graphic method is to estimate the weight of the casting, which is to be made from a given pattern, when the cross-section is not a uniform geometrical figure. Such an estimate is a very important guide to the foundryman, who would otherwise guess at the probable weight of a casting of new design, and, in trying to be on the safe side, would probably melt an unnecessary amount of iron. It is also an aid to the designer of a new car-wheel pattern, who must otherwise estimate from general experience the probable weight, have test-wheels made, and correct the pattern afterwards, so as to obtain the weight prescribed.

For the method here described, an accurate drawing of the pattern is employed. This gives a closer result than a drawing of the wheel itself, for the following reasons:

1. Calculations based upon the actual dimensions of the wheel involve the erroneous assumption that the specific gravity of the casting is uniform throughout; and upon that basis the calculated weight would be wrong, because the amount of metal poured has shrunk in the mould, acquiring the highest density in the outside chilled portion, and growing less dense through the mottled to the gray portions.

2. Calculations based upon the dimensions of the pattern or "chiller" assume that the cooled metal will not have shrunk, but will have the volume of the pattern and a uniform density.

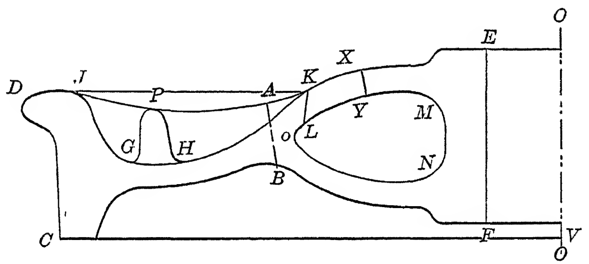
These assumptions, though erroneous, counterbalance each other. For instance, the patterns and the chiller which give a wheel 33 in. in diameter when cold, are respectively 33.5 in. in diameter. This shows a shrinkage for wheel-iron of about $\frac{3}{16}$ in. (ordinary gray pig is commonly assumed to shrink about $\frac{1}{8}$ in.) per foot. Wheels cast in 33.5-in. chillers do not always have the

same diameter. They may vary $\frac{1}{8}$ in. either way by reason of differences in composition, pouring-temperature, duration of pouring, and probably also slight variations in cooling. But the average diameter is 33 in.; and it is found that a calculation based upon the 33.5-in. pattern, and the assumed uniform density of 0.26 lb. per cub. in. of molten wheel-iron, as it fills the mould, gives correct weights of the wheels, even though the latter vary in size, as before explained.

For a casting of uniform specific gravity, either the drawing of the casting, or that of the pattern, could be used. If the latter, then a percentage for shrinkage must be subtracted.

Fig. 1 shows, in reduced size, half the cross-section of the pattern of an ordinary cast-iron car-wheel. From the full-

FIG. 1.



Cross-Section of Half the Pattern. L M N, Cross-section of pan-core. G H P, Cross-section of bracket. E F C D, Cross-section of plates, tread and flange. J P K, Top of brackets. J K, Circle of flange. C V, Circle of rim. O O, Center-line of wheel axis.

sized drawing, divided as shown in the figure, the areas A B C D and E F B A are taken with the planimeter, and the area L M N, similarly determined, is subtracted from their sum. The remainder is the area of the half-section of the pattern, exclusive of the brackets. Let this area (in sq. in.) be called A.

A blue-print is then made, pasted on card-board, cut out along the lines D E F C D and L M N L, and then balanced on a pin-point, to determine the center of gravity of the irregular figure. This point (o in Fig. 1) is located on the tracing, and its distance from the center-line of the wheel-axis, O O, is measured. Let this distance (in inches) be R. If w (0.26 lb.) be taken as the weight of the metal per cub. in., and W as the

weight of the wheel, then $W = 2\pi R \times A \times w$ + weight of brackets and letters, minus weight of metal displaced by the core-legs of the pan-core.

The following calculation for two wheels is given as an example:

I.

The calculation for $2\pi R \times A \times w$ was as follows:

	No. 1.	No. 2.
Area of E F C D, ...	52.38 sq. in.	53.17 sq. in.
Area of L M N, ...	12.42 sq. in.	9.60 sq. in.
Net area (A), ...	39.96 sq. in.	43.57 sq. in.
R, ...	9.38 in.	9.25 in.
Cubic contents of pattern $2\pi R \times A$,	2353.6 cub. in.	2531 cub. in.
Weight (cub. cont. $\times$ 0.26), . .	611.95 lbs.	658 lbs.

II.

The requisite addition for weight of brackets is approximately calculated as follows:

	No. 1.	No. 2.
Area, G P H, ...	2.24 sq. in.	2.30 sq. in.
Assumed average, $\frac{1}{2}$ G P H, . .	1.12 sq. in.	1.15 sq. in.
Average length, measured on curve,	10.5 in.	10.25 in.
Volume of one bracket, . .	11.8 cub. in.	11.8 cub. in.
Weight (vol. $\times$ 0.26), . . .	3.06 lbs.	3.06 lbs.
Weight of 13 brackets, . . .	39.78 lbs.	
Weight of 15 brackets, . . .		45.9 lbs.

NOTE.—The 650-lb. wheels have 13, and the 700-lb. wheels, 15 brackets.

III.

The weight of the letters was obtained by weighing the same letters cast in lead, and taking seven-tenths of the result as correct for iron. This gave, for each wheel, 1.2 lbs.

IV.

The amount to be subtracted for the metal displaced by the core-legs was calculated as follows:

	No. 1.	No. 2.
Thickness ($x\,y$) of bottom plate, . .	$\frac{29}{32}$ in.	$1\frac{3}{32}$ in.
Approx. av. diam. of core-legs, . .	$2\frac{3}{8}$ in.	$2\frac{5}{8}$ in.
Area of base of equiv. cylinder, . .	4.4 sq. in.	5.9 sq. in.
Volume of equiv. cylinder, . . .	4 cub. in.	6.5 cub. in.
Weight (vol. $\times$ 0.26) for 1 core-leg, .	1 lb.	1.7 lbs.
Weight (vol. $\times$ 0.26) for 3 core-legs, .	3 lbs.	5.1 lbs.

V.

The final net weight for each wheel was determined as follows:

No. 1.	611.95 + 39.78 + 1.2 — 3 = 649.93 lbs.
No. 2.	658 + 45.9 + 1.2 — 5.1 = 700.00 lbs.

The calculation for No. 1 was made from the pattern-drawing for a 650-lb. wheel; that for No. 2 from the pattern-drawing for a 700-lb. wheel. The cleaned wheels made from these patterns are averaging 655 and from 700 to 705 lbs. respectively.

Since a variation of 2 per cent. above or below the regular weight can be easily caused by variable moulding in the making of a car-wheel, it will be seen that the foregoing method of calculation gives reliable results. For castings of soft iron, and of more regular shape than car-wheels, even better results could be obtained.

Determining the Size of Hoisting-Plants.

BY EDWARD B. DURHAM, E.M., TRENTON, N. J.

(New York and Philadelphia Meeting, February and May, 1902.)

It is often necessary to calculate the size of a hoisting-plant required to raise a given quantity of material, either as a preliminary to the detail design of the machinery, or to decide whether machinery on hand or offered by a manufacturer is adapted to the work to be done.

The first element of the problem to be determined is the load to be raised. In a mine that is already developed, this is limited by the size of car that can be hoisted out of the mine and that will pass through the underground gangways. If these place no limits on the design, the size of the load will depend on the output desired per day, and on the number of hoists that can be made per day. The latter are fixed by the time required per hoist and the number of hours available for hoisting, after deducting from the working-day the time required for raising and lowering men, sending down supplies, and for the many small delays in handling cars. It must also be decided whether the hoisting is to be done in one shift or in all of them.

As an example, assume an output of 400 tons per 10 hours; shaft, with two compartments, 1000 ft. deep; hoisting in balance; time available for hoisting, 6 h.; engine can hoist load in 1.5 min., and time to change cars 0.5 min. (the change at top and bottom of shaft being made at the same time). Then, 30 cars can be raised per hour, or 180 cars in 6 hours. This would require cars of $400 \div 180 = 2.22$ tons capacity, to handle the desired output.

With a single shaft, the time to raise one load is the time to change or load cars at the bottom, hoist loads, change cars or dump at the top, and lower the empty cars; while, in a double shaft, two cars could be handled while the above programme was being carried out in a single shaft, as the second load would be raised while the first empty was going back down, and changing of cars at the top and bottom would be going on simultaneously.

Ropes.—Having settled the size of the useful load to be hoisted, the size of the rope must be determined. This must be strong enough to hoist the total load, including its own weight, and to withstand the starting-stresses due to picking up the load suddenly when the rope is slack. Experiments have shown that, in starting with six inches of slack rope, the stress in the rope is about double that due to picking up the load gently.

Expressing these stresses in a formula, let

K = stress in rope in pounds, at the head sheave, at the instant of picking up the load.

W = weight of gross load in pounds.

R = weight of rope in pounds.

F = friction in pounds = weight of all moving parts multiplied by f.

f = coefficient of friction.

Then $K = 2W + R + F$. (1)

This stress should not exceed $\frac{1}{7}$ of the ultimate strength of the rope. The coefficient of friction, f, may be taken as .01 for vertical shafts, and as .02 to .04 for inclined shafts with rope well supported on rollers.

As an example, required to find size of rope necessary to hoist a total load of 5000 lbs. from a vertical shaft 1500 ft. deep. Assume, for a trial solution, that rope weighs 2 lbs. per

ft. From equation 1, K=5000 lbs. $\times$ 2 + 1500 $\times$ 2 lbs. + .01 $\times$ 8000 lbs. = 13,080 lbs., and ultimate strength of rope should be $7 \times 13{,}080 = 91{,}560$ lbs., which would require a $1\frac{1}{4}$-inch-diameter flexible cast-steel rope, having an ultimate strength of 100,000 lbs., and weighing 2.45 lbs. per ft. This weight would increase R in above equation, and make $7 \times K = 96{,}285$, which is still less than the ultimate strength of the rope chosen. If a rope of lighter weight is desired, a plow-steel rope could be used instead of the cast-steel.

If the shaft is inclined, the stress in the rope due to the weight hoisted will vary with the sine of the angle of inclination, thus:

$$K = (2\,W + R)\sin x + F, \qquad (2)$$

in which x is the angle of inclination. Here the friction is also affected by the slope, and varies with the cosine of x, or $F = f\,(W + R)\cos x$; f may be taken as .02.

In the following discussion the loads will be considered as being hoisted from vertical shafts, as the principle remains the same for both classes, the only difference being that the stresses in the rope and on the engine and other parts of the machinery change with changes in the slope.

Drums.—The minimum diameter of the drums is determined by the size of the rope used, and the larger the drums the smaller will be the bending-stresses and the more strength will be available for useful work.

Mr. William Hewitt has shown that, when the diameter of the sheave or drum is 44.5 times the diameter of a 19-wire cast-steel rope, the bending-stresses are $\frac{2}{3}$ and the remaining useful strength is $\frac{1}{3}$ of the "maximum safe load" that the rope will carry. The "maximum safe load" is taken as $\frac{1}{3}$ the ultimate strength. This is well below the elastic limit of the wire. Thus the available strength is only $\frac{1}{9}$ of the ultimate. In order to cut down the bending-stresses so as to leave $\frac{1}{5}$ of the ultimate strength of the rope available for useful work, the sheaves must be about 80 times the diameter of the rope. Other grades of rope require different diameter of drums, as will be seen by studying Tables I. and II.

Table II. is based on the formula $k = \dfrac{E\,a}{2.06\,\dfrac{R}{d} + C}$, in which

TABLE I.—*Hoisting-Ropes of* 6 *Strands of* 19 *Wires Each.*

			Iron.		Cast-Steel.		Extra Strong Cast-Steel.		Plow-Steel.		
Diameter in Inches.	Approximate Circumference in Inches.	Estimated Weight per Foot in lbs.	Approximate Breaking-Stress in lbs.	Max. Safe Stress in lbs. = ⅓ Ult. Stress.	Approximate Breaking-Stress in lbs.	Max. Safe Stress in lbs. = ⅓ Ult. Stress.	Approximate Breaking-Stress in lbs.	Max. Safe Stress in lbs. = ⅓ Ult. Stress.	Approximate Breaking-Stress in lbs.	Max. Safe Stress in lbs. = ⅓ Ult. Stress.	Proper Working-Load.
2¼	7⅛	8 00	156,000	52,000	312,000	104,000	364,000	121,333	416,000	138,667	Max. safe stress less bending-stress determined by Table II.
2	6¼	6.30	124,000	41,333	248,000	82,667	288,000	96,000	330,000	110,000	
1¾	5½	4.85	96,000	32,000	192,000	64,000	224,000	74,667	256,000	85,333	
1⅝	5	4.15	84,000	28,000	168,000	56,000	194,000	64,667	222,000	74,000	
1½	4¾	3.55	72,000	24,000	144,000	48,000	168,000	56,000	192,000	64,000	
1⅜	4¼	3.00	62,000	20,667	124,000	41,333	144,000	48,000	161,000	54,667	
1¼	4	2.45	50,000	16,667	100,000	33,333	116,000	38,667	134,000	44,667	
1⅛	3½	2.00	42,000	14,000	84,000	28,000	98,000	32,667	112,000	37,333	
1	3	1.58	34,000	11,333	68,000	22,667	78,000	26,000	88,000	29,333	
⅞	2¾	1.20	26,000	8,667	52,000	17,333	60,000	20,000	68,000	22,667	
¾	2¼	0.89	19,400	6,467	38,800	12,933	44,000	14,667	50,000	16,667	
⅝	2	0.62	13,600	4,533	27,200	9,067	31,600	10,533	36,000	12,000	
9/16	1¾	0.50	11,000	3,667	22,000	7,333	25,400	8,467	29,000	9,667	
½	1½	0 39	8,800	2,933	17,600	5,867	20,200	6,733	22,800	7,600	
7/16	1¼	0.30	6,800	2,267	13,600	4,533	15,600	5,200	17,700	5,900	
⅜	1⅛	0.22	5,000	1,667	10,000	3,333	11,560	3,853	13,100	4,367	
5/16	1	0.15	3,400	1,133	6,800	2,267	8,100	2,700	....	....	....
¼	¾	0.10	2,400	800	4,800	1,600	5,400	1.800	....	.. ..	. .....
Tensile strength of wire per sq. in.			75,000 to 90,000 lbs.		150,000 to 200,000 lbs.		190,000 to 225,000 lbs.		225,000 to 275,000 lbs		

k represents the bending-stress in pounds, *E* the modulus of elasticity $= 28{,}500{,}000$, *a* the aggregate area of the wires in square inches, *R* the radius of the bend in inches, *d* the diameter of the individual wires in inches, and *C* a constant depending on the number of wires in the strand. The values of *d* and *C* are, for 19-wire hoisting-rope: $d = \frac{1}{15}$ diameter of rope, and $C = 45.9$.*

As an example, required the working-load of a 1-in. cast-steel rope running over a 6-ft. sheave. From Table II. the bending-stress is found to be 9937 lbs., and from Table I. the "maximum safe stress" is found to be 22,667 lbs. The difference, 12,730 lbs., is the working-load.

The size of the rope fixes the minimum diameter of the

* Tables I. and II. were calculated by Mr. William Hewitt, and are published here by his permission. The originals, with other data on wire ropes, appeared in a pamphlet entitled "Wire Rope and its Application to Power Transmission," 1901, issued by Trenton Iron Co., Trenton, N. J., from whom copies can be obtained.

TABLE II.—*Bending-Stresses of* 19-*wire Rope.*

Diam. of Bend. / Diam. of Rope.	6	8	10	12	14	16	18	20	22	24	26
$\frac{1}{4}$	1,801	1,390	1,131	965	827	726	654	586	535	495	455
$\frac{5}{16}$	3,308	2,568	2,098	1,774	1,536	1,355	1,212	1,096	1,000	920	852
$\frac{3}{8}$	......	3,776	3,094	2,620	2,273	2,006	1,796	1,626	1,485	1,366	1,265
$\frac{7}{16}$	......	......	5.351	4,546	3,951	3,494	3,132	2,838	2,594	2,389	2,214
$\frac{1}{2}$	......	......	......	6,609	5,755	5,096	4,573	4,147	3,793	3,495	3,241
$\frac{9}{16}$	......	......	......	......	8,337	7,393	6,642	6,029	5,519	5,089	4,721
$\frac{5}{8}$	......	......	......	......	11,565	10,270	9,237	8,392	7,689	7,095	6,586
$\frac{11}{16}$	......	......	......	......	......	13,360	12,027	10,936	10,027	9,257	8,597
$\frac{3}{4}$	......	......	......	......	......	......	15,309	13,932	12,782	11,807	10,971
$\frac{7}{8}$	......	......	......	......	......	......	......	21,403	19,662	18,183	16,910
1	......	......	......	......	......	......	......	......	......	27,612	25,707
$1\frac{1}{8}$	......	......	......	......	......	......	......	......	......	......	35,620

Diam. of Bend. / Diam. of Rope.	28	30	36	48	60	72	84	96	108	120
$\frac{1}{4}$	423	398	338	250	200	167	144	126	112	101
$\frac{5}{16}$	795	742	621	468	376	314	270	236	210	189
$\frac{3}{8}$	1,178	1,102	924	698	561	469	403	353	314	283
$\frac{7}{16}$	2,063	1,931	1,620	1,226	986	824	708	621	553	498
$\frac{1}{2}$	3,021	2,829	2,376	1,800	1,448	1,212	1,042	913	813	733
$\frac{9}{16}$	4,403	4,125	3,468	2,630	2,118	1,773	1,525	1,338	1,191	1,074
$\frac{5}{8}$	6,145	5,759	4,847	3,680	2,967	2,485	2,137	1,876	1,671	1,506
$\frac{11}{16}$	8,024	7,524	6,201	4,818	3,886	3,257	2,802	2,459	2,191	1,976
$\frac{3}{4}$	10,245	9,609	8,101	6,165	4,977	4,173	3,591	3,153	2,809	2,534
$\frac{7}{8}$	15,805	14,835	12,528	9.556	7,724	6,481	5,583	4,886	4,371	3,943
1	24,047	22,589	19,113	14,614	11,830	9,937	8,566	7,528	6,714	6,059
$1\frac{1}{8}$	33,347	31,347	26,566	20,357	16,500	13,872	11,966	10,523	9,387	8,474
$1\frac{1}{4}$	......	42,036	35,683	27,400	22,239	18,713	16,153	14,209	12,682	11,452
$1\frac{3}{8}$	......	......	48,109	37,028	30,096	25,350	21,897	19,272	17,209	15,545
$1\frac{1}{2}$	......	......	61,238	47,229	38,436	32,403	28,008	24,662	22,030	19,906
$1\frac{5}{8}$	......	......	......	59,094	48,152	40,629	35,140	30,957	27,664	25,005
$1\frac{3}{4}$	......	......	......	74,565	60,844	49,919	44,476	39,203	35,048	31,689
$1\frac{7}{8}$	......	......	......	90,325	73,795	62,379	54,022	47,639	42,606	38,534
2	......	......	......	......	88,409	74,795	64,814	57,183	51,160	46,285
$2\frac{1}{4}$	......	......	......	......	125,387	106,265	92,203	81,428	72,908	66,002
$2\frac{1}{2}$	......	......	......	......	......	145,246	126,185	111,546	99,951	90,540

drum, but questions of speed and length of drum also influence the final choice of the diameter.

The maximum length of a drum, aside from question of room, is controlled by the allowable fleet-angle, that is, the acute angle included between two lines drawn from the ends of the drum to the head sheave. This angle should not exceed 6°, in order that the rope may lead well on to the head sheave, and so that one rope will not grind or mount the next one in winding onto the drum. It is usual to place the drum far enough back from the head sheave to keep the fleet-angle within the limit; but where it cannot be done, it is necessary to guide the rope onto the head sheave and onto the drum by rollers or sheaves running on vertical spindles. The bisectrix of the fleet-angle should strike the middle of the drum.

Types of Hoisting-Engines.—Single-cylinder engines are used in mining to replace man- or animal-power for light work.

They are always geared and provided with a fly-wheel on the crank-shaft. They must be started to a fair speed, in order that the fly-wheel may develop sufficient momentum to carry the crank over the center, before the friction is thrown in to pick up the load. The cylinder should have 75 per cent. more power than is necessary simply to raise the load, in order that speed may be maintained.

Double-cylinder engines are used for all the regular work of mining. They may be divided into the following classes:

I. *Geared*:—Single Cylindrical Drum.
Double Cylindrical Drum.
Double Conical Drum.

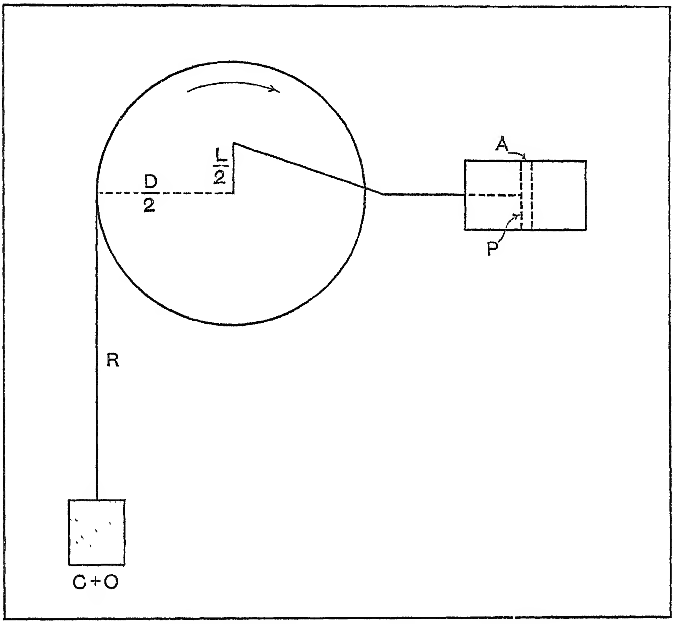
II. *Direct Acting*:—Single Cylindrical Drum.
Double Cylindrical Drum.
Double Conical Drum.
Koepe System.
Reels for flat rope.

Each of these has a field of its own to which it is best adapted. Thus, the geared engine is used mostly for shallow depths and small outputs per day, while the direct-acting engine is used where the output is large. There are many cases near the dividing-line in which either type of engine will give equally good results, and it is largely a matter of personal choice as to which is used.

Geared engines are made with small cylinders, and the engine proper runs at a speed of 100 to 200 r. p. m. The gearing usually gives a reduction of $\frac{1}{4}$ to $\frac{1}{5}$, so that the drum revolves at a moderate speed. The small cylinders make the first cost lower than that of a direct-acting engine; but the gearing for large hoists is a serious objection. The main gear has about the same diameter as the drum, so as to keep the pressure on the teeth as low as possible; and hence it has a circumferential speed equal to the speed of hoisting. Gearing, under very favorable conditions, should not run at a speed over 1200 ft. per min., and with the large cast gears and the rough work to which hoisting-engines are subjected, the speed should probably not exceed 900 ft. per min. If the average speed of hoisting is kept at about $\frac{2}{3}$ of this maximum, the average speed will not exceed 600 ft. per min. This speed will allow the use of moderate-sized drums and keep the piston-speeds within the limits of good practice.

That gearing is liable to cause trouble and make considerable noise when run at a high speed, has been forcibly impressed on the mind of the writer by his experience in charge of a geared hoister, made by a reliable manufacturer, having cylinders each 18 in. dia. by 24 in. stroke, and two drums, each 7 ft. 6 in. dia. by 5 ft. face, on which three main gears, between 7 and 8 ft. dia., 3 in. pitch, and 9 in. face, were broken inside of nine months. The gears cost about $300 each, besides the labor of replacing and the loss of 24 hours in changing the old for a new

FIG 1



SINGLE CYLINDRICAL DRUM ENGINE

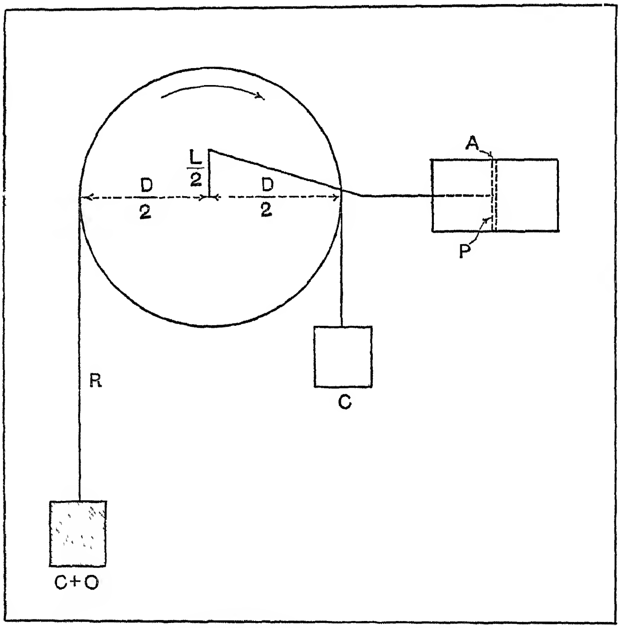
one. The engine was hoisting from a shaft 1000 ft. deep in about $1\frac{1}{4}$ min. The load of ore was $2\frac{1}{2}$ tons.

Direct-acting engines should not be used for hoisting-speeds of less than 500 ft. per min., as the piston-speed will be too slow for economy. They can readily be run at an average speed of 1500 ft. per min., and the largest engines can be run as much as 2500 ft. per min., if the shafts are deep.

Single-drum engines are limited to small outputs per day, or to places where the first cost of the plant is so important as to outweigh the loss in increased operating-expenses. This type

of engine has many applications, as for sinking winzes, and for other inside work; also for shaft-sinking, and for working coal-mines on a small scale, where the cost of fuel is small, as waste material is burned. They are largely used in the Joplin, Mo., district, where the hoisting is from vertical shafts 100 ft. deep, the output often only 25 to 50 tons per day, and the ore is raised in buckets without guides, thus keeping the dead weight small, as compared with weight of ore raised. They are not adapted for regular mining work on a large scale, as the work

FIG. 2



DOUBLE CYLINDRICAL DRUM ENGINE

expended in raising the cage, car and rope, each trip, would exceed the work of raising the ore.

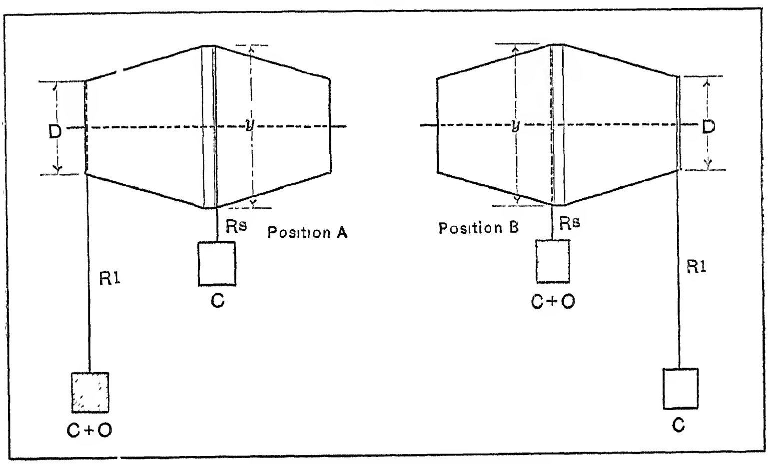
Double-drum engines overcome the dead-work of hoisting the ore-carriers by balancing the weight of the cage and car in one compartment against those in the other. They are thus more economical to operate than a single-drum engine, and the cost of installing will probably not be over 50 per cent. greater than for a single-drum engine. The cost of sinking a shaft large enough for two hoisting-compartments and a manway is not much more than that of a shaft with only one hoisting-compart-

ment and a manway; the head buildings must be nearly the same in either case; and the double-drum engine will have smaller cylinders, thus partly offsetting the cost of the second drum.

With cylindrical drums, the ropes in the two compartments, from the cages to the head sheaves, are of constantly varying lengths, and are in balance only when the cages are passing at the center. With double conical drums, the work on the engine is kept constant by giving the cage at the bottom the short leverage of the small end of the drum, and the cage at the top the longer leverage of the large end of the drum.

The Koepe system, as applied to a double-compartment shaft, has a tail-rope passing from the bottom of one cage down and

FIG 3



DOUBLE CONICAL DRUM ENGINE

around an idle sheave at the bottom of the shaft, and up to the other cage. Thus the weight of the rope in the two compartments is exactly equal, and the whole hoisting mechanism is in balance at all points of the trip.

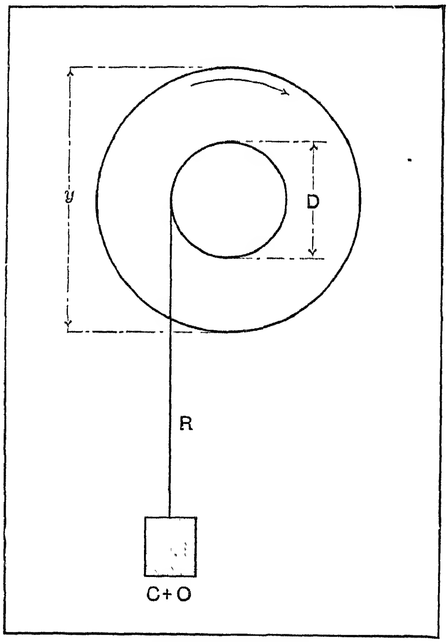
The flat-rope system of hoisting attempts to equalize the work on the engine by coiling a rope of rectangular cross-section on a reel, like a surveyor's linen tape; so that the diameter of the reel increases and the leverage of the load increases as the weight of the constantly shortening rope decreases. Thus the work on the engine is kept constant, when the rate of increase of leverage and decrease of weight are in inverse proportion to each other. The flat ropes, however, are heavier

than round ropes of the same strength, are shorter-lived, and cost more at first and for subsequent care. The flat-rope system is very largely used in Montana, and in some other districts which have followed the Montana practice.

The peculiarities of the different types of engines are brought out more fully by the calculation of the size of their cylinders when equipped with the different arrangements of drums.

Calculation of the Cylinders.—The maximum work on the engine is in picking up the load and in overcoming its inertia.

FIG 4



FLAT ROPE REEL

At this time one crank may be on a dead center, so that all the work must be done by the other. At this part of the hoist, steam will be admitted for the full stroke and at its maximum throttle-pressure.

Hoisting-engines belong to the slow-speed type of engines. Their valves are simple slide-valves in all but the largest sizes, and then they are usually of the Corliss class. They seldom have governing-devices, their speed being determined by the hoisting-engineer by means of the throttle, the link-motion and the brake.

With these classes of engines the piston-speed may be taken at 200 to 400 ft. per min. for engines of 12- to 24-in. stroke, and from 400 to 600 ft. per min. for those with 24- to 72-in. strokes. Very high-grade engines, with other valve-gearing, may run at higher piston-speeds.

At the instant of starting, the power in one cylinder acting on the crank, in the top or bottom position, must have a moment equal to or greater than the moment of the unbalanced load pulling from the circumference of the drum. After starting, the other cylinder comes in to accelerate the speed, and the two together are able to hoist the load with steam partially cut off and still maintain the full speed.

In all the following equations, let

W = weight of unbalanced load in pounds.

C = weight of cage and car, O = weight of ore, and

R = weight of rope, all in pounds.

D = diameter of drum in feet.

$P = M\ E\ P$ = mean effective steam-pressure in cylinder in lbs. per sq. inch.

A = area of cylinder in sq. inches.

L = length of stroke in feet.

S = speed of hoisting in ft. per min.

N = number of revolutions of engine per min.

F = friction in pounds.

f = coefficient of friction.

r = ratio of diameter of piston to length of stroke, both being in feet or both in inches, $= \frac{\text{stroke}}{\text{diameter}}$.

d = diameter of piston in inches.

e = efficiency of engine.

g = ratio of gearing $= \frac{\text{diameter of gear}}{\text{diameter of pinion}}$.

Then, for a single-drum, direct-acting engine, Fig. 1, the moment of the load $= (W + F)\frac{D}{2}$ and the moment of the engine $= (P \times A \times e)\frac{L}{2}$. Placing these equal to each other,

$$\frac{(W + F)D}{2} = \frac{P \times A \times L \times e}{2}. \qquad (4)$$

If the drum is geared, the engine will make g revolutions to

one of the drum, or the leverage of the engine is increased to g times what it would be if directly connected, and the equation becomes

$$\frac{(W+F)D}{2} = \frac{P \times A \times L \times e \times g}{2}. \qquad (5)$$

This is the general equation for all hoisting-engines. If they are directly connected, the ratio of gearing, g, equals 1.

When the weight of the load, size of the drum, and steam pressure are given to determine the size of the cylinders, there are two unknown quantities in the equation, viz.: A and L. Here L can be assumed and the equation solved for A, from which the diameter can be obtained. The usual practice is so to proportion the cylinder that the length of travel is $1\frac{1}{4}$ to $2\frac{1}{2}$ times the diameter of the piston. If the value of L chosen for trial gives a ratio of stroke to diameter outside of these limits, another value must be taken for L, and another solution made. If the ratio is decided upon first, then the area can be expressed in terms of the stroke, and there is only one unknown quantity in the equation. Thus $rd = 12L$ or $d = \frac{12L}{r}$ (12L being the length of the stroke in inches), and $A = \pi\frac{d^2}{4} = \pi\frac{144L^2}{4r^2}$; which, substituted in equation 5, gives

$$\frac{(W+F)D}{2} = P \times \pi\frac{144L^2}{4r^2} \times \frac{L}{2} \times e \times g. \qquad (6)$$

Having obtained the size of cylinders, and knowing the speed of hoisting and size of drum, the speed of the engine can be obtained, and the speed of the piston can be investigated. The speed of hoisting, in feet per min., divided by the circumference in feet, will give the number of revolutions of the drum per minute. If the drum is geared, the engine will make g times as many r. p. m. (revolutions per minute) as the drum, and

$$N = \frac{S}{\pi D} g. \qquad (7)$$

The piston-speed in feet per min. $= 2L \times N$, or

$$\text{Piston-speed} = \frac{2LS}{\pi D} g. \qquad (8)$$

Where the engine is direct-acting, $g = 1$ in both equations, 7 and 8.

The horse-power available for hoisting when the engine is running at full speed will be expressed by the formula:

$$\text{H. P. of engine} = \frac{P \times L \times A \times 2N}{33000} \times e, \qquad (9)$$

and the horse-power required to raise the load will be:

$$\text{H. P. of load} = \frac{(W + F)\,S}{33000}. \qquad (10)$$

In the examples here given the weight of the car is taken as $\frac{2}{5}$, and the weight of the cage as $\frac{3}{5}$ of the weight of the ore hoisted. These together make the dead load, C, equal to the weight of the ore, O. These are sufficiently close to the usual practice for an illustration of the method of using the formulas.

As an example, take a double-cylinder engine geared to a single drum, to find the size of cylinders required under the following known conditions: Vertical shaft is 400 ft. deep, cage to be hoisted in one minute; the weights are, cage 900 lbs., car 600 lbs., ore 1500 lbs., rope 400 lbs.; steam pressure, P, is 60 lbs., $e = 0.7$, $g = \frac{4}{1}$, $f = .01$ (assumed), $D = 4$ ft. and L may be taken as $1\frac{1}{2}$ ft. for a trial solution; then,

$W = C + O + R = (600 + 900) + 1500 + (400 \times 1) = 3400$ lbs.

$F = Wf = 34$ lbs. Substituting in equation 5,

$$(W + F)\frac{D}{2} = P \times A \times \frac{L}{2} \times e \times g, \text{ we have}$$

$$(3400 + 34)\frac{4}{2} = 60 \times A \times \frac{1\frac{1}{2}}{2} \times 0.7 \times 4, \text{ whence}$$

$$A = 54.5, \text{ and}$$

$$d = 2\sqrt{\frac{A}{\pi}} = 8.33; \text{ say } 8\tfrac{1}{2} \text{ in.}$$

The stroke, L, was taken as 18 inches for a trial solution, and this gives a well-proportioned cylinder, viz., $8\frac{1}{2}$ in. in dia. x 18 in. stroke.

The speed of the piston can be tested by equation 8:

$$\text{Piston-speed} = \frac{2LS}{\pi D}g = \frac{2 \times 1\frac{1}{2} \times 400 \times 4}{3.1416 \times 4} = 382 \text{ ft. per min.},$$

which is within the limits for these engines.

From equations 9 and 10 combined, the mean effective-pressure required in the cylinders to perform the work can be determined. Substituting the known values in these equations, placing one equal to the other, and solving, we have

$$\text{H. P.} = \frac{(W+F)S}{33000} = \frac{P \times L \times A \times 2N}{33000} \times e, \text{ or}$$

$$\frac{3434 \times 400}{33000} = P \times \tfrac{3}{2} \times \frac{2 \times 56.75}{33000} \times 2 \times \left(\frac{400 \times 4}{3.1416 \times 4}\right) \times 0.7,$$

$$\text{whence, } P = 45,$$

which, with 60 lbs. at throttle, corresponds to a cut-off of about $\frac{1}{2}$. As both cylinders are in use, the area has been doubled in the above calculation.

With double-drum hoisters, where the descending cage and car counterbalance the ascending ones, the general equation 5 still applies, but the value of W and F are changed. Referring to Fig. 2, when a loaded car is to be started from the bottom of the shaft and an empty car is being lowered at the same time,

$$W = (R + C + O) - C = R + O, \text{ and}$$
$$F = (R + 2C + O)\, f,$$

which values must be used in the first member of equation 5.

As an example, take a hoister raising a load from a double-compartment shaft 2000 ft. deep in one minute: $O = 5000$ lbs., $C = 5000$ lbs., $R = 6000$ lbs., $D = 8$ ft., $P = 60$ lbs., engine directly connected (hence $g = 1$), $f = 0.01$, $e = 0.7$. Taking $L = 4$ ft. for a trial and substituting in equation 5 to find the size of cylinders,

$$(W+F)\frac{D}{2} = P \times A \times \frac{L}{2} \times e \times g,$$

$$(11000 + 210)\frac{8}{2} = 60 \times A \times \frac{4}{2} \times 0.7 \times 1,$$

$$A = 534,$$

$$d = 2\sqrt{\frac{A}{\pi}} = 26\tfrac{1}{8} \text{ in.}$$

This gives a cylinder $26\frac{1}{8}$ in. in diameter by 48 in. stroke.

Determining the piston-speed by equation 8,

$$\text{Piston-speed} = \frac{2LS}{\pi D}g = \frac{2 \times 4 \times 2000 \times 1}{3.1416 \times 8} = 637 \text{ ft. per min.}$$

While the proportions of the cylinders follow the usual practice, the piston-speed exceeds the limits previously set for this class of engines, viz., 400 to 600 ft. per min. This speed can be reduced by choosing a smaller value for L in equation 5, which will give a cylinder larger in diameter. Thus, if the length had been taken as 44 in., or $L = 3\frac{2}{3}$ ft., d would have been $27\frac{1}{4}$ in., and the ratio $\frac{12L}{d} = 1.6+$, and the piston-speed = 584 ft. per min.

Or, instead of shortening the stroke, the number of revolutions can be cut down by increasing the diameter of the drum; thus, if D = 9 ft. and L = 4 ft., d will be $27\frac{3}{4}$ in., the ratio $\frac{12L}{d}$ = 1.73, and the piston-speed = 566 ft. per min.

Conical drums, as already noted, are intended to equalize the varying load on the engine, due to the change in length and weight of the rope as the cage ascends and descends. As these engines are used where every economy is desirable, they are usually direct-acting and fitted with double drums.

The minimum diameter of the drums is determined by the size of the rope.

Referring to Fig. 3, let D represent the small diameter of the drum in feet;

y = diameter of large end of drum in feet.

C = weight of cage and car in pounds.

O = weight of ore in pounds.

Rl = weight of the long length of rope when cage is at the bottom of the shaft.

Rs = weight of the short length of rope when cage is at the top of the shaft.

Then,

$(C + O + Rl)\frac{D}{2} - (C + Rs)\frac{y}{2}$ = moment of the resistance when the load is at the bottom, Fig. 3, position A, and $(C + O + Rs)\frac{y}{2} - (C + Rl)\frac{D}{2}$ = moment of the resistance when the load is at the top, Fig. 3, position B. The object of the conical drums

being to keep this moment constant, these two values must be equal, and

$$(C + O + Rl)\,D - (C + Rs)\,y = (C + O + Rs)\,y - (C + Rl)\,D \quad (11)$$

Solve for y. Then, taking either end case, say when the load is at the bottom, the moment of the resistance of the loads, with friction added, must equal the moment of the power of the engine. This, following the same form as equation 5, gives:

$$(C + O + Rl)\,(1 + f)\,\frac{D}{2} - (C + Rs)\,(1 - f)\,\frac{y}{2} = P \times A \times \frac{L}{2} \times e \times g. \quad (12)$$

Taking as an example the one used for the engine with double cylindrical drums, depth of shaft 2000 ft. plus $33\frac{1}{3}$ ft. to head sheave above landing, S = 2000 ft. per min., O = 5000 lbs., C = 5000 lbs., R*l*. = 6100 lbs., R*s*. = 100 lbs., D = 7 ft., P = 60 lbs., g = 1, f = .01, e = 0.7, L for trial = 4 ft., to find diameter of cylinder.

From equation 11,

$$(C + O + Rl)\,D - (C + Rs)\,y = (C + O + Rs)\,y - (C + Rl)\,D,$$
$$(16100 \times 7) - (5100\,y) \quad (10100y) - (11100 \times 7),$$

whence, y = 12.52 ft. = diameter of large end of drum.

Substituting in equation 12,

$$C + O + Rl = 5000 + 5000 + 6100 = 16100 \text{ lbs.},$$
$$1 + f = 1.01,$$
$$C + Rs = 5000 + 100 = 5100 \text{ lbs.},$$
$1 - f = 0.99$, we have

$$\left(16100 \times 1.01 \times \frac{7}{2}\right) - \left(5100 \times 0.99 \times \frac{12.52}{2}\right) = 60 \times A \times \frac{4}{2} \times 0.7 \times 1,$$

$$56914 - 31607 = 84\,A,$$

whence A = 301, and

$$d = 2\sqrt{\frac{A}{\pi}} = 19\tfrac{5}{8} \text{ in.}$$

From equation 8

$$\text{Piston-speed} = \frac{2LS}{\pi D}\,g = \frac{2 \times 4 \times 2000}{\pi\,\dfrac{(7 + 12.52)}{2}} = 522 \text{ ft. per min.}$$

D being taken here as the mean diameter.

There must be a division left between the ropes on a conical drum in order to furnish positive grooves for the rope, so that the large coils cannot slip down over the smaller ones; hence the drum must be longer than those of the cylindrical design, even when the mean diameter of the conical drum is the same as the diameter of a cylindrical one.

In the Koepe system, as applied to a double-compartment shaft, there is a tail-rope of the same weight as the hoisting-rope fastened to the bottom of one of the cages, passed around a sheave in a pit at the bottom of the shaft, and attached to the bottom of the other cage. Then, in whatever position the cages are in the shaft, there is the same weight of rope hanging in each compartment. Thus the entire weight of the hoisting mechanism is in perfect balance at all times, and the engine only has to raise the weight of the ore and overcome the friction of the moving parts. The main rope may be wound on a pair of cylindrical drums, or it can be wrapped back and forth over a pair of multiple-grooved sheaves, as is done in rope drives for many purposes. It is essential that a positive grip is taken on the rope by the driving mechanism, or else its creeping on the driving-sheaves will make the indicators show a false position for the cages, and make accidents of overwinding a great source of danger.

The calculation of the size of the engines required can be made by equation 5. The engines would usually be direct-acting.

As an example, assume the same conditions as have been used before:

S = 2000 ft. per min. O = 5000 lbs. C = 5000 lbs. R = 6000 lbs. P = 60 lbs., e = 0.7, f = 0.01, g = 1, D = 8 ft., L = 4 ft., for trial.

$$(W + F)\frac{D}{2} = P \times A \times \frac{L}{2} \times e \times g. \qquad (5)$$

W = O = 5000 lbs. $F = f(O + 2C + 2R) = 0.01 \times 27000 = 270.$

$$(5000 + 270)\frac{8}{2} = 60 \times A \times \frac{4}{2} \times 0.7 \times 1.$$

$$A = 251.$$

$$d = 2\sqrt{\frac{A}{\pi}} = 18 \text{ in.}$$

This is a rather small diameter for a cylinder of this length, as its length is $2\frac{5}{8}$ times the diameter, which exceeds the ratio already recommended. If L were taken as 36 inches, the area would be 335 sq. in., corresponding to $20\frac{5}{8}$ in. diameter, which gives a cylinder with better proportions.

The piston-speed can be obtained from equation 8, and the mean effective-pressure required, when hoisting at full speed, can be found from equations 9 and 10 combined.

It is interesting to compare the sizes of the three types of engines, hoisting the same load at the same speed. These tabulated are:

Type.	Dia. of Drum.	$(W+F)\frac{D}{2}$	Dia. of Cylinder.
Cylindrical Drums, ...	9.76	59198	29
Conical Drums, ...	9.76	24669	$19\frac{5}{8}$
Koepe System, ...	9.76	25727	$19\frac{3}{4}$

The conditions in all of the above were the same as used in former examples, except that the diameters of drums are all taken as 9.76 ft., which is the mean diameter of the conical drums. The engines are direct-acting, the shaft has double compartments, and the cages work in balance; $C = 5000$ lbs., $O = 5000$ lbs., $R = 6100$ lbs., $P = 60$ lbs., $L = 4$ ft., $f = .01$, $e = 0.7$, $g = 1$, $S = 2000$ ft. The piston-speed is 522 ft. per min. in each case.

The table shows that cylindrical drums are not as economical to operate as either the conical drums or the Koepe system. The conical drums are expensive to make, as the grooves have to be formed spirally and with an increasing radius, and each problem requires a specially-designed drum, so there can be little use made of stock patterns. They are only used where the rope is heavy, and the economy of accurate counter-balancing is clearly indicated, and will offset the extra cost of manufacture.

The Koepe system is a simple method of counter-balancing, and the principle could often be applied to existing plants with cylindrical drums by adding a tail-rope and an idle sheave at the bottom of the shaft, provided there is sufficient sump-room for the sheave and its slide. The objection to the Koepe system, where used without drums, is the liability of the ropes to creep on the sheaves, causing the indicators to give a false record and so increase the danger of overwinding.

Flat ropes of rectangular cross-section are wound on a reel like a tape. When the load starts from the bottom of the shaft the rope winds on the center of the reel, which is of small diameter, and then, as the load rises, the successive layers increase the diameter of the coil on the reel; thus the leverage of the load increases and the weight decreases. If the original diameter of the barrel of the reel and the thickness of the rope are properly chosen, the moment of the resistance will be constant.

The proportions of the reel can be found as follows:

Let D = diameter of the barrel in feet.

y = diameter of coil of rope, when cage is at the top, in ft.

C = weight of cage and car, O = weight of ore, and R = weight of rope, all in pounds, as before.

l = length of rope or depth of shaft in feet.

t = thickness of rope in inches.

n = number of layers of rope in coil.

Then, referring to Fig. 4, $\frac{y+D}{2}\pi \times n = l$, and $\frac{(y-D)\,12}{2t} = n$.

Substituting the latter value of n in the first equation gives

$$\frac{y+D}{2}\pi \times \frac{(y-D)12}{2t} = l.$$

$$(y^2 - D^2)\frac{3\pi}{t} = l. \qquad (13)$$

From equation 13, knowing t, the value of y can be obtained, or having decided on y, the equation can be solved for t. The minimum diameter of the barrel, D, depends on the thickness of the rope, and can be calculated from Mr. Hewitt's equation, previously given: $k = \dfrac{E\,a}{2.06\frac{R}{d} + C}$, in which k = bending-stress in pounds, E = modulus of elasticity = 28,500,000, a = aggregate area of the wire in sq. in., R = radius of the bend in inches, d = diameter of individual wires, and C a constant depending on the number of wires in a strand. With flat rope, d = $\frac{1}{6}$ the thickness of the rope, and C = 27.54.

The moment of the resistance at starting the load would be the moment of the weight, C + O + R plus the friction, acting with the lever arm $\frac{D}{2}$, as in equation 5.

The ideal case would be one in which the work of hoisting was constant at every part of the hoist; but the thickness of the rope may be such that the leverage of the load increases faster or slower than the weight of the load decreases, thus making the work on the engine to vary during the trip. In such a case, the design must be tested with the cage at various points, to make sure that the engine has sufficient power to handle the loads at the desired speed at all points. For this, equations 9 and 10 may be used.

Generally these hoists are arranged in pairs, so that one cage ascends while the other descends. Then the necessary large diameter of the reel, to make the work constant on the engine, can be found by equation 11, used for conical drums, and the size of the engine from equation 12. After this the thickness of the rope can be found by equation 13.

If the reels cannot be made of such diameter as to make the work of hoisting uniform throughout the trip, with a reasonable thickness of rope, then the case must be considered by itself, and the design must be tested with the cage in positions sufficiently numerous to prove that the engine that will start the load is strong enough to handle it at all points.

The Present Situation as to Specifications for Steel Rails.

BY WILLIAM R. WEBSTER, PHILADELPHIA, PA.

(New York and Philadelphia Meeting, February and May, 1902.)

At the Richmond meeting in February, 1901, I presented for discussion the *proposed* rail-specifications of Committee No. 1 of the American Section of the International Association for Testing Materials, with a review of their work, and other matters relating to the heat-treatment and chemical composition of steel (*Trans.*, xxxi., 455). In order to bring out the views of our members on the important points referred to, I offered for discussion the following questions and comments (*Trans.*, xxxi., 972):

"1. The advantages to be gained by using more metal in the flanges and web of the heavier sections of rails.

"2. The advantages and disadvantages of using a higher-carbon steel than that called for in the specifications under consideration in this discussion.

"3. The amount of shrinkage in a 30-ft. rail, to be specified as an accurate check on the finishing-temperature in rolling.

"4. The advisability of requiring a drop-test on each blow of steel.

"I appreciate that it is not only the finishing-temperature which must be considered, but that sufficient work must be put on the steel at a temperature low enough to break up the coarse structure and produce the tough steel desired. This is recognized by some who are rolling rails direct from the ingot; and they claim that better results are produced by this method than by re-heating the bloom. This might be considered another point for discussion."

We had, on the points thus raised, a very good discussion, bringing out clearly their value and mutual bearing, and undoubtedly exerting an important influence on the general study of the subject. All these points have been taken up since that meeting by other technical societies and by railroad companies, and have been either recognized in commercial specifications, or made subjects of further investigation.

In March, 1901, the Rail-Committee of the American Railway Engineering and Maintenance of Way Association submitted, as a matter of information, to the annual convention of that Association at Chicago, these rail-specifications, with my Richmond paper. The Committee reported in favor of using 33-ft., instead of 30-ft., rails, since cars were now built long enough to carry them, and 10 per cent. of the joints would be saved by their use. As to the proposed change of section, the Report said:

"We feel hesitancy in suggesting new sections; but if all rails hereafter are to be rolled at a lower temperature, we think the section should be modified, and that the sooner the change is made the better for all concerned. This matter has been developed so recently that we are not prepared to submit new sections. However, the A. S. C. E. sections are not the only ones that will have to be modified on account of this change in finishing-temperature; but other sections will have to be modified in the same way—that is, by providing additional metal in the flange."

In the discussion the point was made that it might be a mistake, in rolling with steel of the present carbon-tenor, to rely altogether on the lower finishing-temperature for securing a better quality of rail, thus sacrificing the advantages of the higher carbon, which could be used with safety in rails finished at a lower temperature, so as to realize the advantages of both high carbon and low heat.

This led to my communication of March 25, 1901, to the American Society of Civil Engineers, requesting the appointment of a committee to investigate and report on standard rail-sections, and giving the reasons why the matter should be taken up.

The Board of Direction of that Society made the following report at the annual convention of June 25, 1901:

"ARGUMENTS IN FAVOR.

"1. The American Society of Civil Engineers has already recognized this subject as a proper one for consideration and report by a Special Committee.

"2. The Special Committee, thus authorized, became convinced that experience in the use of steel rails had reached a stage at which standard patterns were not only feasible but desirable, and accordingly, in August, 1893, recommended a series of rail-sections for given weights per yard.

"3. The result of the report of the Special Committee may be indicated by these two facts: 1. That in February, 1881, the rail-mills in this country had 188 different patterns which were considered standard, and that 119 patterns of 27 different weights per yard were regularly manufactured. 2. That in 1899, or six years after the publication of the report of the Special Committee, fully 75 per cent. of all the rails rolled in the United States were of the pattern recommended in that report.

"4. It would seem, therefore, that a suggestion that these sections are in any respect unsatisfactory should not be disregarded; for if the sections now recognized as standard are to be modified in any respect, such modification should have an endorsement of significance equal to that given to the original sections.

"5. To investigate and report upon engineering matters which are of general interest to the profession is a distinctly proper function of this Society. It is submitted that a report from a Special Committee on Rail-Sections should summarize the present state of the art of rail-making, and cover an investigation of all questions relating thereto, whether of section, composition of the material, or processes of manufacture; and that such a report, whether it recommended a change in any of the sections heretofore established or not, would be of great value.

"ARGUMENTS AGAINST.

"1. The rail-sections recommended by the Special Committee of the Society in 1893 have been very generally adopted, and are now recognized as standard.

"2. Well-established standards should not be questioned without good reasons, and no Special Committee should be appointed to reconsider the present standard sections unless upon evidence that a change of section is necessary or advisable.

"3. No such evidence has been placed before the Society or the Board of Direction.

"4. In any case, it does not appear that a Special Committee, if appointed, should be limited by its instructions to the consideration of proposed changes in section alone, as questions of composition and manufacture may be quite as influential in any failure of the present standard sections to meet requirements which may be demonstrated.

"RECOMMENDATION.

"After careful consideration, the Board of Direction, believing that the reasons in favor of the appointment of the proposed Committee outweigh those against such appointment, makes the following recommendation:

"That a Special Committee be appointed, as provided in the Constitution of the Society, for the following purposes:

"1. To report upon the results obtained in the use of rails of the sections presented to the Society in Annual Convention, August 2, 1893, by a Special Committee appointed for that purpose.

"2. To report whether any modification of any of said sections is advisable, and, if so, to recommend such modification.

"3. To report upon the recognized practice as to chemical composition and mechanical treatment used in the manufacture of rails, and the manner of inspection of the same.

"4. To report upon the advisability of the establishment of a form of specification covering the manufacture and inspection of rails.

"5. If found advisable, to recommend a form of specification for the manufacture and inspection of rails."

This report was discussed; and the result of the subsequent postal ballot was greatly in favor of the appointment of the Committee. This appointment has recently been made; and the Committee has been instructed to report on the five points recommended by the Board of Direction.

There is no intention to change the section of the rails, if the mills, by changing their methods of rolling, can produce better structural results in heavier rails. On the other hand, if this cannot be done, and if, by a change of section, the manufacturers can produce a much better rail, the engineers are willing to meet them half-way, and decide the matter on its merits.

At their annual meeting in Niagara Falls, in June last, the American Section of the International Association for Testing Materials adopted their rail-specifications.

On October 1, 1901, the Pennsylvania Railroad Company embodied in its new rail-specifications the minimum shrinkage clause for a 30-ft. rail, as follows:

"The number of passes and speed of train shall be so regulated that on leaving the rolls at the final pass the temperature of the rail will not exceed that which requires a shrinkage-allowance at the hot-saws of more than $5\frac{1}{2}$ in. for 85-lb. and $5\frac{5}{8}$ in. for 100-lb. rails; and no artificial means of cooling the rails shall be used between the finishing-pass and hot-saws."

They also made a new departure in the chemical composition of their steel, decreasing the carbon and manganese when the

phosphorus is over 0.07 per cent., in order to give steel of equivalent hardness and avoid getting steel too hard and brittle. The clause is as follows:

"The steel of which the rails are rolled shall contain not less than 0.40 nor more than 0.55 of 1 per cent. of carbon, where the phosphorus exceeds 0.07 of 1 per cent. Where the phosphorus is 0.07 of 1 per cent. or less, the carbon shall not be less than 0.45 nor more than 0.60 of 1 per cent. The manganese in no case shall exceed 1.20 per cent.; and where the phosphorus exceeds 0.07 of 1 per cent., the manganese shall not be higher than 1 per cent. Also, in no case shall the phosphorus exceed 0.10 of 1 per cent."

In addition to the above, the company now advocates higher carbons, since its drop-tests show that rails finished at a lower temperature give a greater deflection than formerly, when finished at the higher temperature. They also find that higher carbons can be used with safety when the proper check is kept on the lower finishing-temperature. They specify a deflection of not more than $3\frac{3}{4}$ in. for 100-lb. rails after the first blow.

In March, 1902, the Rail-Committee of the American Railway Engineering and Maintenance of Way Association reported to the annual convention several modifications in rail-specifications, the most important of which were a drop-test from each heat of steel, instead of one from each fifth heat, and the introduction of a minimum-shrinkage clause. They did not specify the amount of shrinkage, as they desire to investigate this matter further.

The height of drop specified for the heavier weights of rails was thought by some of the members to be too small in comparison with the height for the lighter rails. This point will be investigated and reported on.

The specifications, with the modifications referred to (and some other minor ones), were adopted by the Association as its Standard Rail-Specifications.

In the same report, the Committee said:

"The rail-mills have furnished the percentage of their total output of rails rolled to A. S. C. E. Section during 1901, as follows:

	Per cent.
National Steel Co.,	95.0
Pennsylvania Steel Co.,	93.2
Illinois Steel Co.,	70.0
Cambria Steel Co.,	73.5
Carnegie Steel Co.,	72.0
Maryland Steel Co.,	52.1
Lackawanna Steel Co.,	37.2

"The low percentage of A. S. C. E. output from the Maryland Steel Co. is explained by the fact that a large amount of rail of special pattern was rolled for export; also that the Pennsylvania lines east of Pittsburg, and the Baltimore & Ohio Railroad Co., used special patterns.

"The Lackawanna Steel Company rolled a large tonnage of the Dudley pattern for the New York Central lines."

The next step will be for Committee No. 1 of the American Section of the International Association for Testing Materials to take up for consideration the modifications of its specifications made at Chicago, and report them at the annual meeting in Atlantic City, N. J., on June 12, 13 and 14, 1902. A cordial invitation will be extended to the members of all Committees and Associations who have discussed these rail-specifications to attend and take part in the discussion. There is little doubt that the modified specifications will be approved by the American Section.

I have stated the present situation in detail, because the subject is one of the most important now before us, and contributions from all quarters will be pertinent, useful and welcome. The work thus far done will naturally form a basis for the new Rail-Committee of the American Society of Civil Engineers, which has been directed to report a form of rail-specification covering both the manufacture and the inspection of rails. That body will, no doubt, improve on the present specification, and bring matters up to date in every particular. When this has been done, the other societies will, no doubt, accept the result; and it is not too much to expect that we shall soon have in use American standard rail-specifications reflecting credit upon all who have assisted in this important work.

The International Railway Congress meets at Washington, D. C., in 1905; and the presentation on that occasion of such specifications, expressing a general agreement in American theory and practice, would, without doubt, greatly influence the action of the Congress in this department.

Specifications for Steel Forgings and Steel Castings.

BY WILLIAM R. WEBSTER, PHILADELPHIA, PA.

(New York and Philadelphia Meeting, February and May, 1902.)

IN view of the good results which have followed the wide discussion of the rail-specifications of the American Section of the International Association for Testing Materials, I now offer for discussion its specifications for steel forgings and steel castings. It is not necessary to emphasize the importance of reaching definite conclusions on these subjects. Engineers, consumers and manufacturers are alike interested in securing good, reliable, uniform steel.

In this connection, I would call particular attention to the important paper read by Mr. C. H. Ridsdale, last September, before the Iron and Steel Institute, as bearing on them; and, for convenience of reference in the discussion, I append the Table in Section VI. of his paper, on "Manifestations, Classified under Heads of Faults of Different Types, appearing after Treatment by the User, for Tracing their Probable Source."*

The discussion of these specifications will be practically a continuation of our former discussions on "The Physics of Steel."

We have passed through a period in which the chemical composition of steel has received the greatest prominence; but failures of steel forgings and castings of the best chemical composition have shown that we could not control the quality of the finished product by the chemical composition alone. It must be admitted that differences in the physical properties of the steel, greater than those due to small variations in composition, are produced by heat-treatment, both in connection with the mechanical work of forging and otherwise. The present result is a strong tendency to deem the heat-treatment more important than the chemical composition. I think the mean course is the safer. We should give them equal importance; for we know that to produce the best results we must start with a good

* *Jour. I. and S. Inst.*, No 2, pp. 94, 95.

uniform material, and employ also, under intelligent supervision, the best methods of manufacture and subsequent working.

The annealing of forgings and castings is much neglected. The manufacturers who are doing the highest class of work for our Government and other customers, under rigid specifications, assert that all such work should be annealed. Other manufacturers of a cheaper class of work claim that annealing is not necessary, and, in some cases, even go so far as to say it is injurious. They adduce results to prove their assertions. But it is only necessary to repeat the annealing under proper conditions, to prove that the source of such alleged injury was in the method of annealing used. In many cases, attempts are made to anneal forgings that have been finished at too high a temperature, without first allowing them to cool down below the critical point. This is merely slow cooling, and makes the material much worse than it would be if allowed to cool in the air.

In consideration of such controversies, I would suggest that discussion be directed towards the heat-treatment of steel, with an endeavor to decide some of the disputed points, and thus to improve the methods of manufacture.

APPENDIX.

Standard Specifications for Steel Forgings.

Process of Manufacture.

1. Steel for forgings may be made by the open-hearth, crucible or Bessemer process.

Chemical Properties.

2. There will be four classes of steel forgings which shall conform to the following limits in chemical composition:

	Forgings of soft or low carbon steel.	Forgings of carbon steel, not annealed.	Forgings of carbon steel, oil-tempered or annealed.	Forgings of nickel steel, oil-tempered or annealed
	Per cent.	Per cent.	Per cent.	Per cent.
Phosphorus shall not exceed...	0.10	0.06	0.04	0.04
Sulphur " ...	0.10	0.06	0.04	0.04
Nickel ...	......	......	......	3.00–4.00

Table from Mr. Ridsdale's Paper, showing Manifestations, Classified under Heads of Faults of Different Types, appearing after Treatment by the User, for Tracing their Probable Source.

Type of fault and manifestation.	By whom originated (probably), provided material as sent was of composition within limits specified and free from visible defects.*	Probable cause.	Tests for identifying cause.
UNSOUNDNESS—			
Hollowness.	Occasionally (if clean), user	Work at too low temperature, not penetrating mass evenly, and causing "creep" of material,† particularly in forgings‡	Microscope shows abnormally distorted grain, etc.‡
Lamination Seaminess (when machined) Split ends	Generally (always if inclosed slag or dirt found), maker	Segregation and (or) insufficient cropping Rolled from cold sheared bars, some of ends of which have split and not been noticed	Presence of slaggy matter high in manganese. Examine ends of unrolled bars left carefully.
Laps	If clean, roller, whether maker or user. If dirty, or other signs of unsoundness, maker	Pipe in ingot imperfectly cropped, or crack not worked out	Eye or microscope can generally discriminate.
SURFACE DEFECTS—			
Cracks Scabs Spilliness (wire) Blisters (sheets)	Generally (always if inclosed dirt), maker	Cracks, etc., imperfectly rolled up, but closed up enough to escape notice	Eye or microscope shows lapping, and generally scale or dirt.
Blisters (sheets)	If bright inside, but large and isolated, or in groups, maker	Segregation ingot top / Blowholes ingot top } Insufficient cropping	Contain CO and N if formed before annealing. Microscope shows normal-sized grains, and soundness before pickling, or in parts other than actual blisters.
Blisters (sheets)	If bright inside, but small and thickly distributed, probably user	Improper pickling Improper pickling preceded by overheating or soaking	Microscopic examination shows large grain or bands.
	Occasionally, maker	Sponginess, insufficient cropping	Microscope shows unsoundness before pickling, or in parts other than actual blisters.
Streaks	(Unless accompanied by lamination at edges of streaks), user	Foreign substances, as coal, coal ash, scale, etc., rolled into surface through getting between rolls and piece, or between pairs of folded sheets. Frequently sticks more if sheets hotter, and hence softer than usual.	If scraped off, sheet underneath sound. Color and simple test shows what it is. Coal (black) burns brown or white; coal ash brown (oxidized); coal ash white (not oxidized). Scale contains 60–70 per cent. iron.
Indentations Roughness or pitting		Left when foreign substances become detached.	Microscope shows larger grain if heated hotter.‡

Dryness—	Generally ....maker	Red-shortness	Analysis shows S and Mn, and hence if these are at fault.
		Segregated parts in center (least cohesion) not all cropped off	Excess of impurities on insides.
Opening at ends	Occasionally..................user	Overheating, sticking in rolls, etc..............................	Color and scale shows this, and if composition quite suitable for purpose, overheating probable cause.
Red-shortness—...	Frequently (to some extent?)........ ....user	Overheated or "soaked" too long..............................	Generally accompanied by thick scale. Microscope shows large grain or bands outside, good normal grain inside if piece thick enough.
Won't weld well	Frequently (to some extent?)....... ....user	Want of flux	Making welding test with flux.
		Unsuitable quality specified	Analysis in conjunction with purpose shows this
Rough ("saw") edges.. ...	Occasionally. ....maker if all over. ..piece or user	Quality has not sufficient margin of "body".	Analysis in conjunction with purpose shows this.
Won't forge well............	If only part, say one corner...... .... .user	Burnt	Generally accompanied by thick scale. Microscope‡ shows large grain or bands outside, good normal grain inside if piece thick enough.
Brittleness—		Either one or more of the following in greater or less degree:	
Breaks off short............ Cracks in punching, stamping or shearing.	Generally (unless composition seriously at fault), user	If coarse grain: Finished too hot or (Furnace too hot........ ....; Rolled hot to spare machinery ....; Rolled very quickly. ... .; Large sections .. ..) "soaked" too long (Delay in mill—Steel left in furnace, or over night .. ...) Cooled very slowly in large heaps, etc.; Over-annealed.	Fracture generally shows coarse grain. Microscope shows larger grain than normal for that section, or structureless bands, especially at outside of piece.‡
Hardness—			
Won't bend enough......	Generally (unless composition seriously at fault), user	If fine grain: Finished too cold or chilled while at blue heat (First piece ....; "Stalling" of piece or other delay ....; Thin sections..... . ...; Cold floor, etc.. . .. .; Spread too much ....; Rain or intentional watering................. . ...) Cooled rapidly; Omitting annealing where required.	Microscope shows abnormally distorted grain, etc.‡
Won't twist enough (wire)	Generally (unless composition seriously at fault), user		In samples rendered brittle by any of causes named, beating for minute or two to cherry-red and chilling in water if C not over 0.10 per cent, or cooling in air if above this, restores toughness, unless sample has been thoroughly spoiled. Microscopic examination also shows grains restored normal.‡
Punches and shears too hard..............	Generally (unless composition seriously at fault), user	Exceptionally severe pickling; cold drawing, rolling or hammering; or galvanizing.	
Tensile test too hard.	Generally (unless composition seriously at fault), user		

Table from Mr. Ridsdale's Paper, showing Manifestations, Classified under Heads of Faults of Different Types, appearing after Treatment by the User, for Tracing their Probable Source.—Continued.

Type of fault and manifestation.	By whom originated (probably), provided material as sent was of composition within limits specified and free from visible defects.*	Probable cause.	Tests for identifying cause.
OVER-SOFTNESS—			
"Lugging"... Won't cut crisp and turn smooth.	Generally..........................user	Tools too blunt or cut too heavy.................. Unsuitable quality specified.......................... Before asking for harder steel, make sure it will not do harm in other way. Try sharper tools or lighter cut first..............................	Comparative tests, using same tool or drill with pieces considered right, will show whether steel is soft or tools blunt. Microscope may show larger grain.‡
Tests too soft........................	Generally..........................user	Finished rather hotter or cooled slower than usual, sufficiently to make steel softer..	

Excepting most forms of unsoundness, it is probable that faults which affect only a small proportion of the steel, and not a whole cast, are not due to the maker, but to the user, for the composition, if wrong, is so in a whole blow, as there is no material variation between one part and another of the same blow, except that occurring from the outside inward, due to segregation, while any variation in the heat and treatment given by maker does not count, as it is obliterated on reheating by user. Many faults are, however, due to a combination of causes for which both maker and user are in varying degrees responsible. If (1) The steel is normally taxed almost to the limit of its endurance by the processes it is made to go through, (2) The maker has not been clearly informed as to the purpose for which it is intended or treatment it will receive, particularly as to soundness when worked into machined articles, the slightest speck or seaminess in which will condemn them; (3) The characteristics of each make of steel are not studied by the user, but all worked indiscriminately; the maker's responsibility should be less.

* Except in the case of ingots or large blooms, slight surface cracks if chipped deeply.

† Dixon Brunton, "Wire and Wire Drawing," *Journal of the West of Scotland Institute*, No. 4, January, 1900, p. 119. Also "Mannesmann" process is an example.

‡ Ridsdale, "Practical Microscopic Analysis," *Journal of the Iron and Steel Institute*, 1899, No. 2, p 102.

§ Maker for his own sake will keep S and other impurities low, as, if seriously at fault, heavy drafts on ingots at once reveal red-shortness, will not roll down clean, so gets thrown out as defective and does not leave works.

Physical Properties.

3. The minimum physical properties required of the different-sized forgings of each class shall be as follows :

Tensile strength.	Yield point.	Elongation in 2 in.	Contraction of area.	
Pounds per square inch.		Per cent.		
				Soft Steel or Low-Carbon Steel.
58,000	29,000	28	35	For solid or hollow forgings, no diameter or thickness of section to exceed 10 in.
				Carbon-Steel Not Annealed.
75,000	37,500	18	30	For solid or hollow forgings, no diameter or thickness of section to exceed 10 in.
				Carbon-Steel Annealed.
	Elastic limit.			
80,000	40,000	22	35	For solid or hollow forgings, no diameter or thickness of section to exceed 10 in.
75,000	37,500	23	35	For solid forgings, no diameter to exceed 20 in. or thickness of section 15 in.
70,000	35,000	24	30	For solid forgings, over 20 in. in diameter.
				Carbon-Steel, Oil-Tempered.
90,000	55,000	20	45	For solid or hollow forgings, no diameter or thickness of section to exceed 3 in.

Tensile strength.	Elastic limit.	Elongation in 2 in.	Contraction of area.	
Pounds per square inch.		Per cent.		
				Carbon-Steel, Oil-Tempered.
85,000	50,000	22	45	For solid forgings of rectangular sections not exceeding 6 in. in thickness, or hollow forgings the walls of which do not exceed 6 in. in thickness.
80,000	45,000	23	40	For solid forgings of rectangular sections not exceeding 10 in. in thickness, or hollow forgings the walls of which do not exceed 10 in. in thickness.
				Nickel-Steel Annealed.
80,000	50,000	25	45	For solid or hollow forgings, no diameter or thickness of section to exceed 10 in.
80,000	45,000	25	45	For solid forgings, no diameter to exceed 20 in. or thickness of section 15 in.
80,000	45,000	24	40	For solid forgings, over 20 in. in diameter.

				Nickel-Steel, Oil-Tempered.
95,000	65,000	21	50	For solid or hollow forgings, no diameter or thickness of section to exceed 3 in.
90,000	60,000	22	50	For solid forgings of rectangular sections not exceeding 6 in. in thickness, or hollow forgings the walls of which do not exceed 6 in. in thickness.
85,000	55,000	24	45	For solid forgings of rectangular sections not exceeding 10 in. in thickness, or hollow forgings the walls of which do not exceed 10 in. in thickness.

4. A specimen 1 by 0.5 in. shall bend cold 180° without fracture on outside of bent portion, as follows:

Around a diameter of 0.5 in., for forgings of soft steel.

Around a diameter of 1.5 in., for forgings of carbon-steel not annealed.

Around a diameter of 1.5 in., for forgings of carbon-steel annealed, if 20 in. in diameter or over.

Around a diameter of 1 in., for forgings of carbon-steel annealed, if under 20 in. in diameter.

Around a diameter of 1 in., for forgings of carbon-steel oil-tempered.

Around a diameter of 0.5 in., for forgings of nickel-steel annealed.

Around a diameter of 1 in., for forgings of nickel-steel, oil-tempered.

Test-Pieces and Methods of Testing.

5. The standard turned test-specimen, one-half inch (0.5) diameter and 2 in. gauged length, shall be used to determine the physical properties specified in paragraph No. 3.*

6. The number and location of test-specimens to be taken from a melt, blow, or a forging shall depend upon its character and importance, and must, therefore, be regulated by individual cases. The test-specimens shall be cut cold from the forging or full-sized prolongation of same parallel to the axis of the forging and half-way between the center and outside, the specimens to be longitudinal—*i.e.*, the length of the specimen to correspond with the direction in which the metal is most drawn out or worked. When forgings have large ends or collars, the test-specimens shall be taken from a prolongation of the same diameter or section as that of the forging back of the large end or collar. In the case of hollow shafting, either forged or bored, the specimen shall be taken within the finished section prolonged, half-way between the inner and outer surface of the wall of the forging.

7. The specimen for bending-test, 1 by 0.5 in., shall be cut as specified in paragraph No. 6. The bending-test may be made by pressure or by blows.

8. The yield-point specified in paragraph No. 3 shall be determined by the careful observation of the drop of the beam, or halt in the gauge of the testing-machine.

9. The elastic-limit specified in paragraph No. 3 shall be determined by means

* The specifications contain a diagram of the proposed section, omitted here.—R. W. R.

of an extensometer, which is to be attached to the test-specimen in such manner as to show the change in rate of extension under uniform rate of loading, and will be taken at that point where the proportionality changes.

10. Turnings from the tensile-specimen or drillings from the bending-specimen or drillings from the small test-ingot, if preferred by the inspector, shall be used to determine whether or not the steel is within the limits in chemical composition specified in paragraph No. 2.

Finish.

11. Forgings shall be free from cracks, flaws, seams or other injurious imperfections, and shall conform to dimensions shown on drawings furnished by the purchaser, and be made and finished in a workmanlike manner.

Inspection.

12. The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and inspections shall be made at the place of manufacture, prior to shipment.

Standard Specifications for Steel Castings.

Process of Manufacture.

1. Steel for castings may be made by the open-hearth, crucible or Bessemer process. Castings to be annealed or unannealed as specified.

Chemical Properties.

2. Ordinary castings, those in which no physical requirements are specified, shall not contain over 0.40 per cent. of carbon, nor over 0.08 per cent. of phosphorus.

3. Castings which are subjected to physical test shall not contain over 0.05 per cent. of phosphorus, nor over 0.05 per cent of sulphur.

Physical Properties.

4. Tested castings shall be of three classes: "HARD," "MEDIUM," and "SOFT." The minimum physical qualities required in each class shall be as follows:

	Hard castings.	Medium castings.	Soft castings.
Tensile strength, lbs. per sq. in.,	85,000	70,000	60,000
Yield-point, lbs. per sq. in.,	38,250	31,500	27,000
Elongation, per cent. in 2 in.,	15	18	22
Contraction of area, per cent.,	20	25	30

5. A test to destruction may be substituted for the tensile test, in the case of small or unimportant castings, by selecting three castings from a lot. This test shall show the material to be ductile and free from injurious defects, and suitable for the purposes intended. A lot shall consist of all castings from the same melt or blow, annealed in the same furnace charge.

6. Large castings are to be suspended and hammered all over. No cracks, flaws, defects nor weakness shall appear after such treatment.

7. A specimen 1 in. x 0.5 in. shall bend cold around a diameter of 1 in. without fracture on outside of bent portion, through an angle of 120° for "soft" castings, and of 90° for "medium" castings.

Test-Pieces and Methods of Testing.

8. The standard turned test-specimen, 0.5 in. diameter and 2 in. gauged length, shall be used to determine the physical properties specified in paragraph No. 4.*

9. The number of standard test-specimens shall depend upon the character and importance of the castings. A test-piece shall be cut cold from a coupon to be molded and cast on some portion of one or more castings from each melt or blow or from the sink-heads (in case heads of sufficient size are used). The coupon or sink-head must receive the same treatment as the casting or castings, before the specimen is cut out, and before the coupon or sink-head is removed from the casting.

10. One specimen for bending-test 1 in. x 0.5 in. shall be cut cold from the coupon or sink-head of the casting or castings as specified in paragraph No. 9. The bending-test may be made by pressure, or by blows.

11. The yield-point specified in paragraph No. 4 shall be determined by the careful observation of the drop of the beam or halt in the gauge of the testing-machine.

12. Turnings from the tensile specimen, drillings from the bending-specimen, or drillings from small test-ingot, if preferred by the inspector, shall be used to determine whether or not the steel is within the limits in phosphorus and sulphur specified in paragraphs Nos. 2 and 3.

Finish.

13. Castings shall be true to pattern, free from blemishes, flaws or shrinkage-cracks. Bearing surfaces shall be solid, and no porosity shall be allowed in positions where the resistance and value of the casting for the purpose intended will be seriously affected thereby.

Inspection.

14. The inspector representing the purchaser shall have all reasonable facilities afforded to him by the manufacturer to satisfy him that the finished material is furnished in accordance with these specifications. All tests and specifications shall be made at the place of manufacture, prior to shipment.

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* The specifications contain a diagram of the proposed section identical with that in the article on "Steel Forgings," and here omitted.—R. W. R.

The Metallurgy of Titanium.

BY AUGUSTE J. ROSSI, NEW YORK CITY.

(New York and Philadelphia Meeting, February and May, 1902.*)

We cannot expect, within the limits of this paper, to treat this subject exhaustively, but will endeavor, in the following, to present it in as concise a manner as is consistent with a clear exposition of its importance.

Ores of titanium, titaniferous iron-ores (that is, iron-ores containing a notable amount of titanic acid, TiO_2, say not less than 5 per cent., generally 10 to 20 per cent., and frequently more, up to 40 per cent. or thereabout), occur all over the world in immense quantity, "in mountain masses," constituting in some localities, as in Sweden, Norway, Canada, the Adirondacks (N. Y.), in North Carolina and other States of the Union, the geological formation itself, the igneous rocks having, in many places, been so permeated with the metallic oxides as to justify their being called iron-ores.

As a rule they are Bessemer ores, quite free from phosphorus and sulphur, though not invariably so. When the percentage of titanic acid is very high, that of the iron is low, but the proportions do not necessarily vary in the same ratio; that is, a rich ore may contain more titanic acid than one lower in iron. The percentage of iron varies, being as low as 35 to 36 per cent. in real ilmenite. It is more generally not less than 50 to 55 per cent., reaching often an average of 58 to 60 per cent., and as high as 63 to 65 per cent.

It is obvious that if these ores were to be considered in the same light as other iron-ores, equally rich in iron, they would form an excellent stock for blast-furnaces for years to come, as their supply might be called inexhaustible, and they could

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* Secretary's Note.—This paper was prepared for the Franklin Institute, and presented at a joint session of the Mining and Metallurgical Section of that Society with this Institute, held May 15, 1902, at the Manufacturers' Club, Philadelphia.

take the place, in part or wholly, of other iron-ores free from titanium, of which the exhaustion, in a comparatively short time, in certain districts can be foreseen, owing to the tremendous demands made on them by our modern monster blast-furnaces. In this sense we are justified in saying that the metallurgy of titanium is one of pre-eminent importance, as it implies the use of these ores, which may justly be called the resources and reserves of the future, when they will be appreciated at their full value, and the prejudices against them will be removed, as gradually they are getting to be. "The verdict against them," as has been said by others than ourselves in the discussion of some of our papers on the subject, read before the American Institute of Mining Engineers, "is unjust, based on entirely insufficient grounds, and far from creditable to the progressive spirit of American metallurgy."

Generally low in silica, free from impurities, such as phosphorus and sulphur, they are particularly well adapted in the blast-furnace for the production of a stock well suited for the open-hearth process (either acid or basic), which is gradually supplanting, at least competing more seriously with, its rival, "the pneumatic or converter process."

Some of the objections raised against the use of these ores in the blast-furnace are so unreliable, so contradictory, so much in opposition to actual facts, that it is really puzzling to find out on what ground they were originally founded.

Opinions in this respect seem to have been taken already made, without any personal control or even desire to ascertain the authenticity, reality or importance of certain statements, and handed down from one to another.

We have not been able to find one metallurgist who could tell us he had used these ores, or that, using them, he had experienced any trouble thereby. They have brought forward the stereotyped objections and rested there: "*Sit pro ratione voluntas!*"

These objections have appeared in many scientific publications (easily quoted), and often simultaneously with their refutation by actual experiments on the subject. For instance, to mention one of them, it has been stated that the presence, in a blast-furnace slag, of 1 per cent. of titanic acid, or thereabout, was sufficient to render it so infusible as to transcend the heat

capacity of the blast-furnace, the slag being so pasty as to render its tapping impossible, or practically so; and still, slags containing 25 to 35 per cent. of titanic acid have been run for over twenty years from blast-furnaces put up in the Adirondack wilderness some fifty years ago, and thousands of tons of such slags, which we have seen and analyzed, form, at the present day, an embankment around the cast-house of the old furnace, of 15 tons daily capacity, still standing as a testimony that this statement as to infusibility of titanic slags cannot in any manner be sustained.

For seven years blast-furnaces have been run in England, at Norton-on-Tees, with ores containing 40 per cent. of titanic acid and 35 to 36 per cent. of iron, making 200 tons of pig-iron per week. Analyses of the slags have been published by the chemist in charge, as well as all the data as to composition of ores, charges in coke, ore and fluxes. The slag contained, on an average, 36 per cent. of titanic acid.

We ourselves have run for several months a small blast-furnace of 3 to 4 tons capacity, put up at Buffalo, to demonstrate the economy of the smelting of this class of ores when properly dealt with. We have tapped hundreds of tons of slags containing 32 per cent. of titanic acid, which ran 50 feet from the furnace perfectly liquid. In crucible tests that we have made in a furnace with "natural draft," compounds containing 63 to 64 per cent. of titanic acid were obtained, which we have been able to cast in molds.

We give below an analysis of the slags mentioned above as an illustration:

	I.	II.	III.	IV.
Silica, . . .	27.83	26.72	15.90 to 17.50	0.67
Titanic acid, . .	36.18	25.11	34.38	64.80
Lime, . . .	24.36	25.81	22.10	14.30
Alumina, . .	9.18	11.86	11.23	10.50
Magnesia, . .	0.60	5.99	9.70	8.30
Oxide of iron, . .	1.85	3.46	4.30	0.90

I. Slag run at Norton-on-Tees from Norwegian ilmenite containing 40 per cent. of titanic acid, 35 to 36 per cent. iron. Analysis by chemist in charge. Wm. M. Bowron.*

II. Slag run in Adirondacks in 1856. Average specimen from several hundred pounds of slags picked up from the cinder-bank in 1893 by A. J. Rossi. Analysis by Ledoux & Co.

* *Trans.*, xi., 159.

III. Slag run in the small Buffalo furnace, put up in 1896, at the New York Car-Wheel Works, by A. J. Rossi. Analysis by the chemist of the works.

IV. Compound made in crucible in a furnace with natural draft and poured out in molds. The ores used contained 15 per cent. of TiO_2, and on an average 58 per cent. of iron.

Other objections, such as "titanium deposits" in the boshes, according to some, in the hearth, according to others, have been advanced against the use of these ores; and to accept the "sworn testimony" of some blast-furnace managers in a suit in which we were called as expert, "$\frac{3}{4}$ of 1 per cent.," "$\frac{1}{4}$ of 1 per cent.," mere "traces" of titanic acid in an iron-ore, are as sure to produce these deposits as larger percentages. I had been for twelve years technically in charge of the blast-furnaces of Fuller, Lord & Co. (called the Boonton Iron Works), and left in 1876. Our ores contained normally from $\frac{3}{4}$ of 1 per cent. to 1.25 per cent. titanic acid, and never did we observe such deposits in our two furnaces. We did not even at that time attach importance enough to the presence of titanic acid in the ores to determine it in our analyses otherwise than as a curiosity.

As regards larger percentages of titanic acid, the successful and continuous running of the Adirondack furnaces for twenty years, that of the English furnace at Norton-on-Tees for seven years (as attested by a mention of this furnace in a paper read before the British Iron and Steel Institute at their annual meeting in 1894), and that of our own small blast-furnace at Buffalo for some months, ought to dispose of these objections, or at least limit them to special cases, as when, by accident, the objectionable phenomena might have been observed in an abnormal and deranged working of a furnace, smelting, possibly unknowingly, a mixture of ores in which titanic acid was present; and it might well be asked whether such derangement was not *post hoc* rather than *propter hoc*.

It is well known that obstructions of a similar character, and composed almost entirely of lime, have been observed in the smelting of ores free from titanium. One of these infusible blocks in a blast-furnace was stated to weigh 30 tons. The cause of their formation has been attributed to the excess of limestone charged as flux and of lime in the cinder, very basic silicate of lime being quite infusible *per se*. In such conditions titanium deposits may have contributed to the obstruction without being the cause of it.

Some twenty-five or thirty years ago the chemist was a luxury in a blast-furnace plant. A good practical rule of thumb was followed with sufficiently constant success with ores varying but little year after year; but when the demands of industry justified an increase in the number and size of furnaces, and consequently necessitated a more abundant supply of ores, new ores had to be mixed with those generally used; and the presence of titanic acid being likely ignored, as well as the manner of dealing with it properly, fluxes may have been indiscriminately added, causing trouble, and the titanic acid was conveniently made the scapegoat. When we say fluxes, we mean calcite, as, for many years, limestone (calcite) was considered the only admissible or safe flux in a blast-furnace. Indeed, Percy himself, in his admirable and classic book on metallurgy, states that, "as magnesia increases the infusibility of a slag, dolomite as a flux, instead of limestone, should obviously be avoided."

This is another prejudice which has lasted for years, and has been exploded only within the last twenty years, or thereabout. As every metallurgist knows now, dolomite is preferable to calcite as a flux, as it increases the fluidity and fusibility of the slag, at the same time removing sulphur fully as efficaciously if not actually better than lime.

Titanate of lime is more infusible still than silicate of lime, and the addition of lime in excess, on general principles, may possibly, with ores very low in silica and containing a large amount of titanic acid in the mixture, have caused the slag to prove less fusible; but we should not forget, however, that a silico-titanate of lime, containing about equal percentages of silica, titanic acid and lime,—"sphene," as it is called,—is as fusible in a blast-furnace as any good foundry-iron slag, and considerably more fusible than silicate of lime; so that the presence of titanic acid should have increased the fusibility, if a sufficient amount of silica was present, instead of diminishing it. We may refer to Analysis No. I. of the slags run at Norton-on-Tees as an example.

As to "titanium deposits," strictly so called, that is, formations of nitrides and cyano-nitrides of titanium of a copper-red color, or of a metallic titanium, as it was claimed by some, they may have been possible in a serious derangement

of the working of a blast-furnace occurring under circumstances independent of its presence, and due to causes entirely foreign to it; the titanic acid being then an "accessory after the deed," and conveniently assumed to be the principal cause of the mischief.

We have seen in Pittsburg a very fine large specimen of such titanium deposit; it was copper-red and kept religiously under a glass case. But the well-known metallurgist who had it was conscience-stricken, and owned frankly to us that he had had the curiosity to have it analyzed, and that it was found to contain 98½ per cent. of copper. As is well known, for many years, and until the researches of Wöhler, it was believed that titanium was a red metal, like copper.

In short, titanic acid, properly dealt with in the blast-furnace, will not necessarily prove the cause of trouble. Slags containing some 35 per cent. of titanic acid will run as fluid as silica slags; and if in an iron-ore the titanic acid be treated as so much silica, and be depended upon and calculated to form one of the principal elements of the slag, with such amount of silica as will be necessarily and unavoidably contributed to the slag by the limestone, the ores and the ashes of the fuel, and if a dolomitic stone be used as flux instead of a calcite, titano-silicates of lime, alumina and magnesia will be found to form a very fluid fusible and good slag, and no titanium will remain in the furnace to cause any trouble in a normal or ordinary running.

It is this addition of dolomite as a flux, instead of calcite, that we have successfully experimented with in our small furnace at Buffalo. (See analysis of slag III.) Both in the Adirondacks (analysis II.) and in England (analysis I.) at Norton-on-Tees, the composition of the slag was different, in this sense, that titanic acid was present to nearly an equal percentage with lime and silica, reproducing practically the composition of the mineral sphene perfectly fusible in the blast-furnace—*a silico-titanate of lime.*

In England it was obtained by the addition to the ore, of which the composition is given below, of siliceous flux, in the shape of old bricks, besides the calcite addition, considered indispensable at the time.

*Ore Used at Norton-on-Tees—Norway Ilmenite.**

Titanic acid, (average of cargo)	39.20
Silica,	5.70
Ferric oxide,	18.59
Ferrous oxide,	30.00
Manganese oxide,	0.60
Alumina,	2.89
Magnesia,	2.80
	99.78
Iron,	36.34 per cent.

In the Adirondacks, siliceous fluxes were also added, but they were furnished by the Labrador feldspar, costing nothing, and saving a corresponding amount of limestone. The ore, on on average, contained:

Silica,	2.50
Titanic acid,	13.50
Alumina,	1.50
Magnesia,	0.90
Oxide of manganese,	0.13
Phosphorus,	0.020
Sulphur,	0.052
Oxide of iron,	81.90
	100.502
Metallic iron,	58.43 per cent.

We have published on these questions several papers,† to which we refer the reader for more complete information. In one of them will be found all the data of the run of the small experimental furnace erected at Buffalo.

We should remark, here, that all that we have said above applies to ores really titaniferous, containing, say, not less than 5 per cent. titanic acid, smelted alone. As to ores containing 1 per cent of titanic acid or thereabout, our practice of twelve years in Boonton, N. J., and that of other furnace-men who bought from us ores like those we used (or similar ones of Morris county, in which the average of titanic acid is from 0.55 to 1 per cent., such as those of the Hibernia mine, Mount Pleasant), and are using yet, cannot leave any doubt that $\frac{3}{4}$ per cent. to 1 per cent. of titanic acid in the ore mixture can be com-

* Analysis by Wm. M. Bowron, chemist in charge. See Bowron's paper quoted above, *Trans.*, xi., 160.

† "Titaniferous Ores in the Blast-Furnace," *Trans.*, vol. xxi., p. 832. "Smelting of Titaniferous Ores," *Iron Age*, Feb. 6 and 20, 1896.

pletely ignored, so far as affecting in any manner the run of the furnaces or the charges.

But, even assuming an inferior limit of 0.50 per cent. of titanic acid admissible in a mixture, it is difficult to conceive why ores from North Carolina and elsewhere, containing 64 per cent. of iron and 5 per cent. of titanic acid, cannot be used to the extent of 10 per cent. in mixture with ores free from titanic acid, since by so doing the mixture would contain only 0.50 per cent. of titanic acid, an amount present in the charges of a number of blast-furnaces we could quote, and immense deposits of excellent ores thus be made available as blast-furnace stock.

But prejudices are difficult to eradicate when they are deeply rooted, even if arithmetic is resorted to to demonstrate their fallacy.

There is another objection, more specious than real, which has been raised against the smelting of titaniferous iron-ores, namely, that of the relative economy offered. There is no doubt that, with such ores as were used in England at Norton-on-Tees, and which contained only 36 per cent. of iron with 40 per cent. of titanic acid and 10 per cent. of other gangue (in all, 50 per cent. of barren materials), the addition, as flux, of as much lime and as much silica as there was titanic acid in the ores, there must have been about 4½ tons of slag to melt per ton of iron smelted, and the process may not have proved economical as to fuel; but would it have been any more so with ores free from titanium but containing such an amount of gangue and 40 per cent. of silica? In the Adirondacks, the ores being much richer and containing so much less titanic acid (15 per cent. instead of 40 per cent.), the addition of rock as flux did not very materially affect the economy; but in our small furnace at Buffalo, as no other flux but dolomite was added (the titanic acid being treated as so much silica), the smelting proved as economical (as the record of the run showed) as that of any other ore free from titanium and containing the same amount of silica as the Adirondack ores contained of titanic acid.

But this question of economy of fuel, even assuming it were real when dealing with such ores as we might contemplate smelting without admixture, that is, rich ores containing a moderate amount of titanic acid, is of but little importance, if, as

we shall presently see, the properties of the pig-metal yielded by this class of ores are such that it commands a much higher price on the market than an ordinary good foundry-iron.

It is the consensus of opinion, admitted even by those most obstinate in their prejudices, that the pig-iron smelted from really titaniferous ores smelted alone, or in important proportions with other ores, is "strong," "wonderfully good," "a splendid iron," "all that can be desired," for such are the expressions met with at every step when one is referred to the literature of the subject. The iron made at Norton-on-Tees in 1869–1876, it is said in the *Journal of the Iron and Steel Institute*, "went to Sheffield for armor-plates on account of the toughness that this iron not only possesses but imparts to others in admixture."

It is essentially an open-hearth stock. Analyses of the pig-iron made by us at Buffalo and that of the Adirondacks (the same ores were used in both cases) showed phosphorus, traces; silicon, 0.11 to 0.13; carbon, from 1.86 to 3.50, practically all combined; the fracture had very much the appearance of that of steel. It is eminently a chilling-iron, well adapted for car-wheel mixtures. Introduced in such mixtures, not only does it increase the strength of the metal constituting the body of the wheel, but it gives at the tread a deep, strong and hard chill, resisting attrition and shocks remarkably well, as was attested by parties interested in this line of manufacture, and for whom and with whom we have made extensive tests with this special iron.

Briefly stated, the results were as follows: The addition of 5 per cent. of titaniferous pig to a normal mixture for wheels increased the chill on chill-blocks from 1.062 inches to 1.375 inches, and the transverse strength from 3250 pounds to 3775 pounds per square inch. The addition of 10 per cent. of titaniferous pig brought the chill to 1.562 inches, with a transverse strength of 3600 pounds per square inch; and the addition of 25 per cent. of this titaniferous pig, white or mottled white as it was, without affecting the original strength, raised the depth of chill to 1.750 inches.

In another establishment the wheel-mixture showed a tensile strength of 24,500 pounds, and a transverse strength of 2500 pounds per square inch. The addition of 10 to 15 per cent. of

titaniferous pig to a cheap grade of foundry pig, showing only 18,500 pounds tensile strength and 1900 pounds transverse, raised the strength to 25,500 pounds and 2730 pounds, respectively, per square inch, with a much deeper chill than in the wheel-mixture, and at a cost of several dollars less per ton.

Strange as it may appear at first, this titaniferous pig-iron does not contain titanium to any important extent. Rarely does it contain more than a few tenths of 1 per cent.; more generally only a few hundredths of 1 per cent. The influence of titanium in the smelting would seem thus to be one of purification, by eliminating obnoxious elements, more than a direct one; but we shall see later on that it is not necessarily always so. Titanic acid is not reduced by carbon at the temperature attained in a blast-furnace, contrary to what happens with silicon. It requires the high heat of the electric furnace to secure such a reduction. If titanium is found in the pig-iron, to some small extent it is due to certain special reactions, possibly to the presence of alkaline cyanides formed in the vicinity of the tuyeres, forming small quantities of cyano-nitride of titanium, which is carried out by the iron, coating it *superficially*, as has been observed in some furnaces, and giving to the pig-metal a copper-colored hue. This may possibly explain why titanium is found in such small percentages, and why it is not found in the free *metallic* state in the analysis, but as *carbide* and *cyano-nitride*, or both. That titanic acid is not reduced directly by carbon in the blast-furnace, and, if at all, but to a very small amount, seems to be proved by the fact that ores containing as much as 40 per cent. of titanic acid yielded a pig-iron containing titanium 0.00 to 0.03 per cent. (analysis of pig-iron smelted from ilmenite, made at the School of Mines of Paris), while the pig-iron smelted from the Adirondack ores containing 13 to 15 per cent. of titanic acid (TiO_2) analyzed 0.07 to 0.12 per cent. of titanium. The conditions of running of the furnace in both cases seem to have had more to do with the reduction, small as it was, than the percentage of titanium in the ores.

The question suggests itself: Since pig-iron smelted from titaniferous ores, though containing but very small amounts of titanium, and that not in the metallic state, but as carbide or combined with nitrogen and carbon as cyano-nitride, what

would be the effect of the presence of titanium as metal, in more important percentages, in such products as cast-iron or steel?

We know that nickel added to steel, to the extent of 3 to 5 per cent., imparts to it valuable properties; that added even to cast-iron it increases the strength, though at a material increase of cost. We know, also, that chromium and molybdenum have special influences on the properties of steel. Could not titanium, as a metal, impart valuable though different or similar properties? But since pig-iron does not appear to contain titanium to any available extent, and the amount present is not in the form of free titanium, and since, whatever this quantity may be, it disappears in the process of refining pig-iron for making steel, the only way to secure the presence of titanium to any important extent in pig-iron or steel is to add it to the finished product in the state of alloy, as *ferro-titanium*, in the same manner as ferro-chrome or ferro-nickel or ferro-manganese is used to incorporate these metals in steel. Such alloys we have manufactured last year by the ton, and of this manufacture we will now briefly speak:

Professor Moissan, in his well-known experiments on the reduction of refractory metallic oxides, has been able to obtain small quantities of metallic titanium by the reduction of purified rutile (titanic acid, TiO_2) by carbon, in a lime or magnesia crucible, under the influence of the heat secured by a powerful electric current. Moissan's method of using a small furnace, with horizontal electrodes, between which the electric arch was started *above* the materials to be reduced, and not in contact with them, has become classical. But the product obtained contained carbon, and was indeed carbide of titanium for a great part, and had to be purified by repeated treatment with fresh quantities of titanic acid. Such experiments, although of great interest in the laboratory, could not, of course, form the basis for the production of commercial titanium alloys, as the low price of a product is a *sine-qua-non* of its practical use. Furthermore, titanium carbide, as obtained by Moissan experimentally, on a small scale, and which can be obtained on a larger scale much more easily than the metallic titanium, contains *titanium combined* with carbon in definite proportions. It has special properties, principally of hardness, which it may

impart to mixtures; but however valuable these may be, they are quite different from such properties as could be expected from titanium introduced in a metal (such as cast-iron and steel) in the free metallic state, as is nickel, for instance.

By the method we have followed we have manufactured alloys of titanium and iron containing from 10 per cent. to 75 per cent. of titanium, and either practically free from carbon or, if containing carbon, containing it in the *graphitic state;* so that the titanium was present as *free metal* alloyed with iron, and not in the state of carbide.

As the percentage of titanium in these alloys increases, their fusibility diminishes. Thus, 10-per-cent. titanium alloys do not melt at the temperature of fusion of cast-iron and steel, and they are incorporated in the molten mass by a sort of dissolution, just as platinum, infusible at the above-mentioned temperatures, "will fuse in contact with steel at a temperature at which even the steel itself is not affected, alloying in all proportions with iron," as shown by the results obtained by Faraday and Stoddart. Ten-per-cent. titanium alloys containing carbon (graphite) present the appearance of a No. 1 graphitic pig-iron, the particles of graphite shining brilliantly through the mass; they are soft under the hammer, forging and flattening, though quite resisting. However, when once torn apart, so to speak, in small fragments, they flatten to such an extent as to admit of their being easily pulverized. The powder, sifted through an 80-mesh sieve, showed by analysis the same percentage of titanium as the solid piece itself, thus demonstrating a very even dissemination of the graphite through the mass. As the percentage of titanium increases, the grain of the fracture becomes closer, the other characteristics remaining the same.

The titanium alloys, free from carbon, are of a silver-white color, exhibiting a coarse crystalline structure, when the titanium is low (about 10 per cent.), the grain becoming finer as the titanium percentage increases. With 35 per cent. of titanium the fracture is that of a solid mass, showing no crystallization, at least to the naked eye. The color is of a dull silver-white when the alloy contains over 45 per cent. to 50 per cent. of titanium.

All these alloys, the carbon alloys as well as the others,

are much lighter than cast-iron, their specific gravities varying with the amount of titanium. We have found it to be 5.60 for a 25- to 30-per-cent. alloy free from carbon, and about the same (5.74) for a 10- to 12-per-cent. alloy with carbon; metallic titanium having a specific gravity of 4.87, cast-iron one of about 7.00, and wrought-iron one of 7.788.

It would carry us too far to describe in detail the manufacture of these alloys, and we refer the reader to the article on this subject which has appeared in Vol. IX., *Mineral Industry*, 1901. We will briefly recapitulate its salient points:

The electric furnace we used was of the well-known type of the Siemens furnace of 1879, modified to some extent for our purpose. It consisted essentially of a large block or parallelopiped of agglomerated graphite. A cavity in the block formed the crucible or hearth; and in this cavity, by means of a proper system of chains, pulleys, etc., the vertical carbon electrode, or cathode, formed of one or several carbons bunched together, could be worked up and down. The graphite block was connected at its lower part with one of the terminals of the current and formed thus the anode, while the vertical carbon, by means of flexible cables, was connected with the other pole; the materials to be reduced being charged in the cavity of the furnace, and the vertical carbon lowered to almost a contact, the arc was started through the materials of the charges, and the reduction proceeded until completed. The product could be removed at the end of the operation, or the alloy (when liquid) tapped off.

According to size of cavity or crucible, intensity of current and percentage of titanium desired, we could make from 150 to 250 pounds of alloy in about two hours with about 200 horsepower. When making alloy containing carbon, the charges consisted of the titaniferous oxides mixed with the proper amount of carbon, the materials being used in powder and strongly compressed. Some of the ores used were the Adirondack ores mentioned above, which could yield readily an alloy containing from 12 to 13 per cent. of titanium. By using Canadian ores containing 35 per cent. of titanic acid and about 35 per cent. of iron, we obtained alloys containing as much as 35 per cent. of titanium. The use of rutile—natural TiO_2—

nearly pure, and containing about 90 to 95 per cent. of TiO_2, would, of course, have given us alloys as high in titanium as might have been desired; but, until the late discoveries of special, extensive and geologically interesting deposits of rutile in Virginia about one year ago, its cost, $250 to $350 a ton, excluded its use, from the standpoint of economy. Even now, and though rutile has fallen in price to half of what it was, its price is still considerably higher than that of titaniferous ores high in titanium (40 per cent. of titanic acid), which can be had at the cost of ordinary iron ores.

We have obtained from the Adirondack ore containing 58 per cent. of iron and 15 per cent. of titanic acid (TiO_2), or say 9 per cent. of titanium, alloys of 75 to 80 per cent. of titanium by the special method which we have followed,—a sort of igneous concentration, as we call it. The method consisted in submitting in our furnaces a mixture of these Adirondack ores with a quantity of carbon sufficient to reduce the iron oxides, but not the titanic acid, it contained, to a heat but a little higher than that attainable in the blast-furnace, adding to the ore a small quantity of lime or good limestone, so as to form practically, with the titanic acid of the ores, a titanate of lime, with such small amount of magnesia and alumina (or silica) as the Adirondack ores could contribute to the slag. We thus obtained, as a by-product, a titaniferous pig-iron, containing but a few hundredths of 1 per cent. (0.032 per cent.) of titanium and possessing all the valuable properties of the metal smelted in the blast-furnace from this class of ores, and at the same time, as slag, a concentrate of the titanic acid of the ore to the extent of 56 to 58 per cent. of TiO_2 (corresponding in round numbers to 33 or 35 per cent. of titanium) with no more iron than is ordinarily met in a blast-furnace cinder, that is, about 2 per cent. Thus, by treating 100 parts of this concentrate as we did the ore, we could theoretically obtain an alloy containing, say, 31 parts titanium, 2 parts iron, or 94 per cent. titanium; or, by mixing it with proper quantities of iron-ore, secure an alloy containing any percentage of titanium desired. But, as we shall see, this concentrate proved of particular value in the making of alloys free from carbon.

All the alloys made with carbon, as reducing agent, contained from 7.50 to 8.50 per cent. of carbon, and occasionally even 9 per

cent., of which 0.10 per cent. or less was combined carbon, the remainder graphitic carbon. In order to obtain alloys free from carbon, or practically so, we used a method based on the well-known property of aluminum to reduce metallic oxides. This property has formed the subject of many experiments in the laboratory for over fifty years; but it has been considered necessary, for success, to use the aluminum in the form of an impalpable powder, and to mix it, in that state, with the powdered oxide to be reduced.

In recent years Dr. Goldschmidt has succeeded in utilizing industrially, to a certain extent, the reducing power of aluminum in pulverulent form. His method consists, after having mixed intimately together the powdered aluminum and the powdered oxide, in placing in the mass a primer formed of powdered aluminum and an oxide capable of readily yielding a portion of its oxygen, such as sodium or barium peroxide, and starting the primer itself by igniting an inserted ribbon of magnesium. The heat of formation of alumina (in the primer), the aluminum oxidizing at the expense of the oxygen of the oxides, is so intense that, by contiguity, it is imparted to the whole mass, and the reduction proceeds instantaneously, so to speak, often tumultuously and dangerously so, without the intervention of any external heat. It is not for us to discuss the value of this process any further than to say that the rapidity of the reaction itself creates in the metal or alloy obtained a certain uncontrollable amount of aluminum which cannot be removed without a remelting of the product, and that some of the materials of the vessel in which the operation is carried on also pass into the product—silica, if a clay vessel be used; carbon, if a graphite one be resorted to; it cannot be claimed that strictly pure alloys or metals are produced. But the main drawback to its industrial use on a large scale, aside from the manipulations required, is the original cost of the aluminum in powder, which is several times that of aluminum in ingots or scrap.

We have found that it is not necessary to use the aluminum in powder to secure the reducing action, but that if a bath of aluminum be maintained at the proper temperature, in an electric furnace, for instance, like the one mentioned above, the metallic oxides (in this case the titanic acid and the iron oxides

charged in the bath) will be reduced, the temperature rising from the heat of formation of alumina to such an extent as to allow the moderation of the external source of heat first applied until the reduction is complete, or nearly so. The metal or alloy obtained can then be kept liquid by increasing the intensity of the current before being tapped, and easily deprived, by a fresh addition of oxide of iron, of the aluminum it may contain, or, by proper additions, of any other impurities it may be considered desirable to remove.

Furthermore, in the Goldschmidt process, if titaniferous iron-ores are used as raw materials, the amount of powdered aluminum to be added must be such as to reduce also the oxides of iron, which is paying rather dear per pound of iron reduced (as it requires nearly one-half pound of aluminum per pound of iron), and if rutile be used, then its price comes in as a very important factor.

By using, in starting, the titanic concentrate mentioned above as containing about 30 per cent. of titanium and only 2 or 3 per cent. of iron, we have to add aluminum to reduce the titanic acid only, and if lower alloys are wanted, dilute, so to speak, the high alloy obtained, in a bath of iron. In this way we have manufactured alloys of titanium containing from 10 to 75 per cent. of titanium and from 0.10 to 0.60 per cent. of carbon, or thereabout, at a cost not materially higher than for carbon alloys.

In the tests we have made of the titanium alloys for seasoning cast-iron, we have invariably used the carbon alloys, and, by preference, alloys containing 10 to 13 per cent. of titanium. In an experiment with steel we have used the alloys reduced with aluminum and practically free from carbon.

We have added the carbon alloy to cast-iron in the crucible in lumps; in the ladle in small pieces or in powder; in the cupola in large lumps, and also in powder, and the results have been practically the same. An addition of 2 to 3 per cent. or thereabout of a 10-per-cent. titanium alloy appears to be amply sufficient to secure such results as an increase of 20 to 30 per cent. in the tensile strength of cast-iron, and proportionately as much in transverse strength. Results of such tests have appeared in papers read by us before the American Society of Mechanical Engineers (Milwaukee Meeting, May, 1901, Vol. XXII. of *Transactions*) and at the Annual Meeting of the

American Foundrymen's Association, June, 1901, Buffalo (Vol. X., *Transactions*, Part I.), to which papers we refer the reader.

Since then we have made other equally successful tests in different establishments, car-wheel works and others. We will briefly recapitulate them:

In general, the results of tests of 100 square bars 1 by 1 by 12 inches between bearings, and round bars 1⅛ in. in diameter by 18 inches in length, or thereabout, showed that by adding in the cupola, in good-sized lumps, 3 per cent. of a 10-per-cent. alloy, or the same amount in powder in the ladle, we could bring the original strength of a good No. 2 coke-iron, showing 24,500 pounds tensile and 2450 pounds transverse strength per square inch, up to that of an excellent Scotch charcoal pig-iron or higher (in fact, 28,800 pounds tensile and 2900 pounds transverse); and that by a similar addition of alloy to this Scotch charcoal pig we could bring the strength to some 32,500 pounds tensile and nearly 3300 pounds transverse strength. As the price of this charcoal pig-iron was $29 a ton, while that of the coke-iron was $15 at the time, and as they were used in mixture for special foundry purposes, it is clear that a mixture of the coke-iron treated with the alloy and of the coke-iron itself not treated could be used with great advantage as to cost of mixture for the same strength secured; the addition of the alloy to the extent mentioned to the coke-iron increasing the cost of the latter but a fraction of the difference of prices ($15 and $29) between the two original pig-irons.

Our tests with steel have so far been limited to crucible steels, and enough has been observed to show that the influence of titanium, introduced into steel in the metallic state, has been to increase considerably the ductility, as proved by the remarkable elongation, contraction of area and limit of elasticity observed in high-carbon steels containing 1.25 per cent. and even 2 per cent. of carbon. The quantity of titanium found in the steel by analysis varied from 0.89 per cent. and 1.01 per cent. to 0.10 per cent. As the effect of even such small quantities as the latter (0.10 per cent.) was very marked, and as, in these cases, 0.10 per cent. did not represent what could have been expected from the addition of the alloy, the question arises: Has not titanium, when thus added to steel, an indirect action besides a specific one?

It has been suggested that, in the same manner as manganese removes oxygen from steel in the Bessemer process, and also in the open-hearth and even in crucible steel, titanium may act not only as a deoxidizing agent, much more powerful still than manganese, but may also remove from the steel the nitrogen it undoubtedly contains, and which has an unfavorable influence on its strength. (The odor of ammonia so noticeable in the open-hearth process proves the presence of nitrogen very decidedly; and as is well known, titanium burns in nitrogen at 800° C. with incandescence, just as iron burns in oxygen.) If this is so, a use for the alloy, even when containing carbon, might well be found in the open-hearth as also in the converter, since it could be used as a recarburizer, on account of the high percentage of carbon it contains; as a deoxidizer (with or without ferro-manganese); and as a denitrogenizer, so to speak; and, in the case of small converters for steel castings, the heat of formation of titanic acid, which is much higher than that of silica, would prove of advantage in raising the temperature of the bath even were but a small percentage of titanium to remain ultimately in the finished product. If by such use open-hearth and converter steel could be so improved as to compare better as to strength with crucible steels, and the latter be also improved to the extent it appears to have been in our first tests, there would be opened for these alloys a large field of usefulness, and for these titaniferous ores a very important application.

In tests made in some establishments we have used simultaneously the titaniferous pig and the alloy in the cupola, with such a resulting toughness combined with a remarkable hardness and strength of chill in car-wheels that it has justified the statements of some manufacturers as to the importance of these products in the iron industry, when better known. To obtain them cheaply—and we mean by that at such a price that their use would prove economical in view of the results secured—has been our aim.

We may remark here, that if the thickness of a casting can be diminished without impairing its strength—on the contrary, leaving it stronger—the cost of the material which has secured such a result may well be compensated for, and more, by the advantages obtained.

We are continuing our tests along these lines for different establishments, and we may be justified in saying, as a conclusion, that if these tests and those carried on by outside parties (to whom we are willing to extend all facilities to make them), justify our claim, as those already made have done, the importance of the metallurgy of titanium cannot be ignored or overlooked much longer, and that these titaniferous ores, as we said at the outset, will constitute a valuable resource and reserve for the future, both for blast-furnace stock for the manufacture of pig-iron and for metallurgy in general for the production of valuable alloys. Titanium may be found to form alloys with other metals than iron, or with iron and other metals possessing special and valuable qualities. We have had no trouble, by following our aluminum method, in making alloys of titanium and copper, as well as ferro-tungsten, ferro-chromium, ferro-molybdenum (practically free from carbon), and compound alloys of chromium-titanium-iron, etc., of which we are now studying the properties.

The Manganese Industry of the Department of Panama, Republic of Colombia.

BY E. G. WILLIAMS, COLON, COLOMBIA, S. A.

(New Haven Meeting, October, 1902.)

General Description.

Manganese-ore has been found upon the Isthmus of Panama throughout a region of nearly three hundred square miles, over the greater part of which, however, it is known only in small bodies without commercial value.

Only six mines, controlled by two companies, have actually shipped ore, although a large area has been taken up in mining-claims.

The ore-bearing region extends along the coast of the Caribbean Sea, beginning on the west near Puerto Bello and extending easterly about 35 miles toward Point San Blas. Ore has been discovered in the interior, at a maximum distance of about 10 m. from the coast. Fig. 1 is a map of a portion of the Isthmus

of Panama, compiled from the map of Lucien N. B. Wyse, published by the Panama Canal Co., from Government charts, and from surveys of the Caribbean Manganese Co., and showing the manganese-bearing area and the location of the working mines.

The last known ore-deposit to the east is upon the border of the country of the San Blas Indians; and further prospecting in that direction is at present impracticable, on account of their hostility toward strangers. It is probable that the boundaries of the ore-bearing area given above may be considerably extended by future work.

The first shipments from the region were made in 1871, from the village of Viento Frio. This early mining was of a primitive character, and consisted in breaking up surface boulders near the sea and packing the ore down to the coast upon men's backs. Probably 1000 tons of ore was shipped in small vessels, mostly to England, between 1871 and 1875, when the loss of a schooner near Viento Frio caused the abandonment of the work.

In 1880 the manganese properties in the immediate vicinity of Viento Frio were acquired by Mr. W. L. Rathburn, now of New York City.

Mr. Rathburn worked the property for about a year, shipping small lots of ore in schooners, which he had engaged in the cocoanut trade between the Isthmus and New York. The largest shipment was one of 80 tons. This, however, never reached its destination, the schooner foundering at sea.

A shipment to England of 40 tons of high-grade ore showed on analysis 57.87 per cent. of metallic manganese.

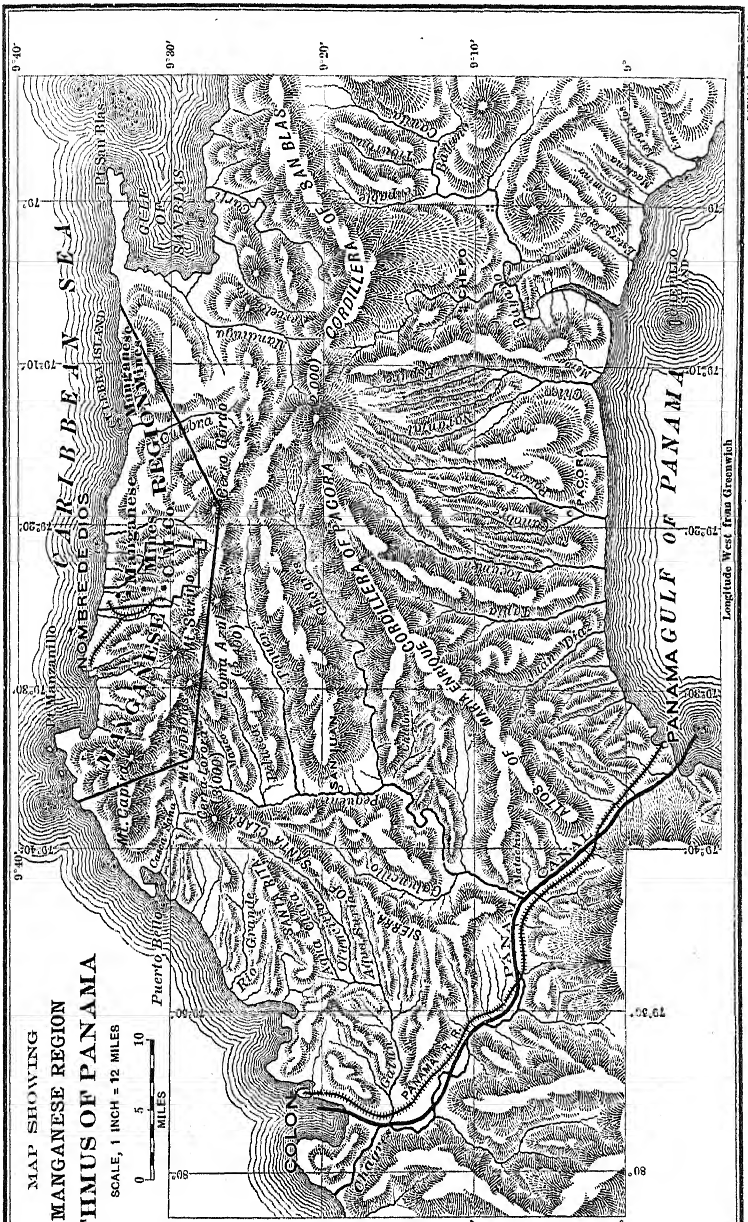
The ore shipped to the United States was ground and sold for chemical purposes.

The ore in sight at that time consisted entirely of surface boulders. An examination of the property by an English engineer engaged by Mr. Rathburn failed to show any suitable ore reserve; and, acting upon the engineer's report, Mr. Rathburn disposed of the property.

The persons who acquired it did not attempt to mine any ore, and nothing further was done until 1890.

Then the discovery, upon the surface about 5 miles south of

Fig. 1.


MAP SHOWING
MANGANESE REGION
ISTHMUS OF PANAMA
SCALE, 1 INCH = 12 MILES
MILES
CARIBBEAN SEA
GULF OF PANAMA
Longitude West from Greenwich
NOMBRE DE DIOS
GULF OF SAN BLAS
Pt. San Blas
MANGANESE REGION
Manganese Mines
CORDILLERA OF SAN BLAS
CORDILLERA OF PACORA
CHEPO
PACORA
Puerto Bello
PANAMA R.R.
PANAMA CANAL
COLON
PANAMA

Viento Frio, of large boulders of high-grade ore, which had been unknown to the early miners, caused a revival of interest in manganese-mining in the locality, and led to the formation of the Caribbean Manganese Company of Baltimore to exploit the deposits.

In 1894 and 1895 the Caribbean Manganese Co. constructed, from the shipping port of Nombre De Dios to the base of the range upon which its principal mine was located, a railroad of 3-ft. gauge, nine miles in length, with maximum grades of 5 per cent. in favor of the traffic, and maximum curves of 40 degrees.

Aside from this company, the only shippers from the region have been the firm of Brandon, Arias & Filippi. The Caribbean Manganese Co. has shipped ore from four properties—the Viento Frio, Carano, Concepcion, and Soledad. The firm named has shipped from the La Guaca and Culebra mines. All the mines mentioned are near the railroad except Culebra, which is situated upon a small island about 12 miles east of Nombre De Dios. Some ore has been mined at Meamar, about midway between Nombre De Dios and Culebra, but none of it has been shipped. Fig. 2 shows the location of the mines adjacent to the railroad.

The total product of the region to date has exceeded 60,000 tons. On account of the revolution in the country, the work has been conducted under great difficulties during the last two years, and at times has been entirely suspended. The restoration of peace will undoubtedly cause a revival of interest in mining throughout the entire country.

The earlier history of manganese-mining in this region has been fully given by Mr. E. J. Chibas in a paper presented before the Institute in 1897,* and the present paper deals mainly with later developments.

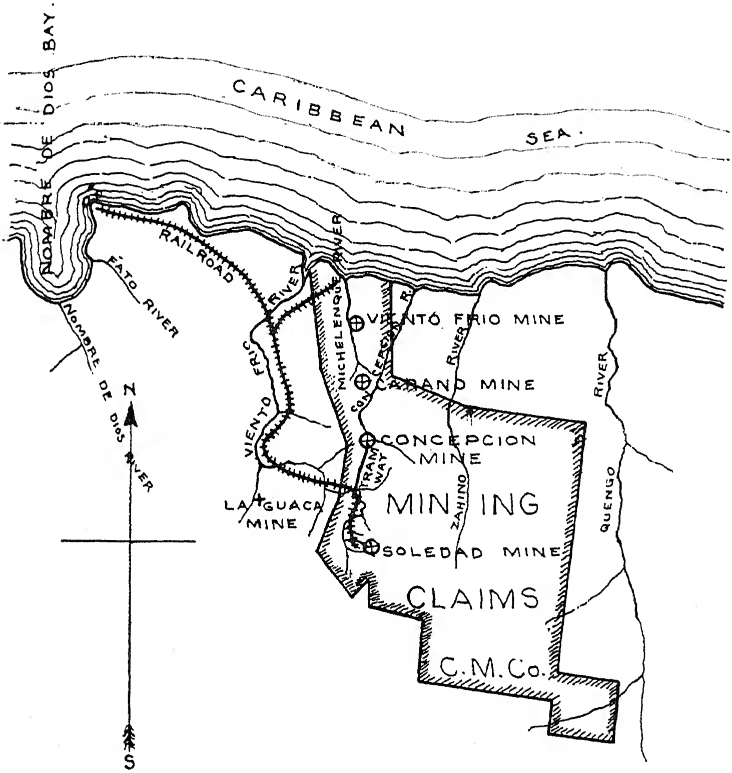
Topography of the Manganese Region.

On entering the Isthmus of Panama, the Western Cordillera of the Andes, which follows the Pacific coast-line of Colombia, divides into a series of parallel ranges which reach a maximum

* *Trans.*, xxvii., 63.

height of about 3000 ft. Fig. 1 shows in the region of the ore-deposits a series of parallel rivers on the Atlantic side, flowing north into the Caribbean Sea; on the Pacific side a series of parallel rivers flowing south into the Pacific Ocean,

FIG. 2.



MAP SHOWING LOCATION OF MINES.
CARIBBEAN MANGANESE CO.
SCALE 1" = 18,400'
0 10,000' 20,000' 30,000'

while the center of the Isthmus is drained by the Chagres and its tributaries, flowing in this portion of their courses in a general westerly direction.

In general, the manganese-deposits are found within the

drainage-areas of the first set of rivers mentioned, flowing north into the Caribbean; although in one instance, at least, a considerable deposit exists within the Chagres drainage-area. All the ore-deposits are upon the Atlantic slope.

At some points within the manganese-bearing area the highland approaches the sea, but often (as around Nombre De Dios) lowland, enclosing swamps and lagoons, extends back from the shore a quarter of a mile or more to the foothills.

The hills rise in a series of parallel ranges, each higher than its predecessor, toward the interior, and the country is very rough and difficult of access. No roads of any description exist; and the usual way of reaching the interior is to paddle up a river as far as a canoe will float, and then wade up in the river-bed to the head of the stream.

The surface-rock has been decomposed to a considerable depth, and the heavy rainfall upon the resulting clay mantle which covers the country has afforded great opportunities for the modelling of the surface by erosion. After a few hours of mountain climbing in the interior, one is usually convinced that Nature has taken full advantage of these opportunities. The streams, except for short distances near the coast, flow in narrow gorges with steep side-slopes, which stand at practically the angle of repose of the surface soil. This is shown, apart from the slope angle, by the numerous landslides after heavy rains, when the soil is saturated to a greater degree than usual. The summits of the divides between the streams are often so narrow as to allow only a footpath upon them.

The manganese-deposits occur upon the comparatively low lands near the sea as well as upon the summits of the hills in the interior, and the Culebra mine is upon an island—a remnant of the mountain spur which here approaches the sea.

Rocks Associated with the Ore-Deposits.

The clay which everywhere covers the surface makes the work of tracing the formations very difficult. Occasional outcrops, through the clay, of rock hardened by metamorphic action, furnish the only evidence.

The rocks immediately associated with the manganese-deposits are all sedimentary formations, but are now so greatly decomposed as to render their original character doubtful,

though, when first formed, they were probably shales. In the vicinity of some of the ore-deposits they have been metamorphosed into a jasper, and thus preserved.

In the bed of the Mamey river, skirting the base of the Soledad mountain, upon which the principal ore-deposit of the region is located, occurs the only rock in the vicinity of any such deposit which appears, even at first sight, to be of igneous origin. But this, upon microscopic examination, proves to be a metamorphosed sedimentary rock, composed of a mixture of volcanic ash and particles of other sedimentary material, apparently derived from the decomposition of an andesite. The rock is highly silicified, and also decayed by weathering, thus making its determination somewhat difficult.

The surface-clays are usually light yellow. Where associated with ore in place, however, the clay is generally bright red; but it is found in all shades from red to white, the varying colors resulting from the various stages of oxidation and hydration of the manganese and iron contained in the clay.

The rocks associated with the ore will be described in greater detail in the description of the various mines. The writer is indebted to Professors S. L. Penfield and L. V. Pirsson, of Yale University, for assistance in the rock-determinations.

Character of the Ore.

The ore occurs as oxides. The principal variety, furnishing the greater part of the commercial ore, is psilomelane. Pyrolusite and braunite also occur. The psilomelane and pyrolusite are intimately associated, one oxide blending into the other without any visible line of separation. It is not uncommon to find in massive psilomelane small cavities filled with pyrolusite, and clusters of pyrolusite crystals have been found radiating from a base of psilomelane. The psilomelane is massive and very hard. It varies in color from black to steel-gray, the steel-gray ore being usually the hardest, and having a conchoidal fracture. The massive psilomelane in large bodies shows numerous fracture-planes (slickensides), and the two adjacent surfaces are often hardened above the general hardness of the ore for a depth of one or two inches, so that it is extremely difficult to temper drill-steel so that it will stand work in them.

The ore classified as braunite is of infrequent occurrence, and consists of small masses made up of numerous small crystals, the whole showing a well-defined crystalline structure, with an irregular fracture. The crystals are iron-gray in color, the color resembling the steel-gray of the massive psilomelane, but not having so brilliant a metallic luster on a fresh fracture. The pyrolusite occurs in fibrous crystals, usually about one-half in. in length, radiating in clusters from a massive base. It also occurs as a granular mass, made up of numerous small crystals. As a source of commercial ore it is not important. Of the crystalline ores, pyrolusite belongs to the orthorhombic system of crystallization, and braunite to the tetragonal.*

* An analysis received by the writer just at the time it was necessary to send this paper to the United States for publication raises a presumption that a portion, at least, of the hard, massive ore described throughout this paper as psilomelane may prove to be a hitherto undiscovered manganese oxide, having the formula $MnO.2MnO_2$, or Mn_3O_5.

Some samples of the purest ore of the Soledad mine were sent to Prof. S. L. Penfield, of Yale University, for a complete analysis, to accompany this article, as representing the character of the high-grade ore of the region. The ore was supposed to be psilomelane, which in appearance it resembles.

The analysis was made by Mr. W. E. Ford, assistant to Prof. Penfield, and gave the following result, as the mean of two analyses which check each other very closely:

Manganese protoxide (MnO),	78.25
Available oxygen (O),	11.83
Copper oxide (CuO),	0.67
Quartz (SiO_2),	2.00
Soluble silica (SiO_2),	2.67
Iron sesquioxide (Fe_2O_3),	0.40
Alumina (Al_2O_3),	0.21
Lime (CaO),	1.32
Magnesia (MgO),	0 16
Potash (K_2O),	0.10
Soda (Na_2O),	0.38
Water (H_2O),	1.70
Phosphoric acid (P_2O_5),	0.03
	99.72
Metallic manganese,	60.60

Mr. Ford remarks, concerning the analysis:

"If all the available oxygen in the ore is calculated as belonging to MnO_2 we should have 64.32 per cent. of MnO_2 and 25.76 of MnO. If we consider it in this way, we have the ratio of $MnO_2 : MnO$ as $0.739 : 0.363$ or as $2.00 : 0.98$, which equals very nearly $2 : 1$. Under this assumption the manganese oxide of the ore has the following formula: $MnO.2MnO_2$, or Mn_3O_5. If, on the other hand, we calculate the manganese in the ore as occurring in the form of Mn_2O_3, we have 87.06 per cent. of Mn_2O_3 and an excess of 3 per cent. of oxygen."

The physical features of the ore vary greatly, and the different oxides apparently blend in all shades of gradation, so that it is usually difficult to identify the mineral species when it is uncrystallized.

Pockets of soft ore, which can be worked without drilling, are sometimes, but not often, found in the hard ore-bodies. Bodies of red clay and ore, interstratified, are found; and ore is also found, but rarely, interstratified with jasper. Occasionally, small masses of concretionary origin occur.

Some of the mines show massive ore almost entirely; in others the ore shows plainly a stratified structure, in which case it is usually of somewhat lower grade than the massive. Where metamorphic action has taken place (as shown by the conversion of the shale to a jasper), the ore is almost invariably massive; and the stratified form, on the other hand, is almost invariably found with the unaltered shale. Hence the massive form is probably the result of a consolidation of the stratified masses by metamorphic action. The higher grade of the massive deposits is probably due to secondary chemical changes. Where manganese oxide which has been subjected to metamorphic ac-

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Prof. Penfield, writing of the mineral, says:

"The mineral is not like any of the well-known manganese species. It is hard, like psilomelane, but contains too little water and too little oxygen. Leaving the small amount of water out of consideration, the mineral agrees very well with the composition $MnO.2MnO_2$, or Mn_3O_5. The close agreement with the formula may be in part accidental, as the material is not crystallized; but, if the specimen sent represents a fair sample of what you are mining, my belief is that you are at work on an ore which deserves a name as a distinct mineral species."

Prof. Penfield also calls attention to the somewhat similar composition of chalcophanite, a hydrous oxide of manganese and zinc, found at Franklin Furnace, N. J., the composition of which, as given by Dana, is $(MnZn)O.2MnO_2.2H_2O$. In this mineral the ratio of $(MnZn)O$ to MnO_2 is the same as that existing in the specimens analyzed from the Soledad mine. In the analyses of chalcophanite given by Dana the proportion of MnO to ZnO is about 1:3. But for the replacement of part of the manganese by zinc, chalcophanite could be considered a hydrous form of the oxide described above. Additional samples of the purest ore obtainable have been sent to Prof. Penfield for a more detailed examination.

As the existence of a new manganese oxide cannot be considered as fully established by the two analyses made, and as the results of further investigations now in progress must be awaited, the designation of the massive ore as psilomelane, previously adopted, has not been changed, especially as psilomelane does occur in the region as a common ore, and the similarity in appearance between it and the new oxide would allow the same general description of physical characteristics to apply to both.

tion is of high grade, or at least is low in silica, it is to be inferred that a low temperature accompanied the change, since, under a high temperature, the ore would have taken up silica from the surrounding rock. There is but little difference in the siliceous contents of the massive and the stratified ore of the region, the former being slightly higher in silica, and also in manganese.

The ore usually requires hand-picking, to keep the silica contents below the allowable limit of 8 per cent., above which the ore has to pay a slight penalty for each additional unit of silica. The siliceous ore is easily recognized by its appearance. The ore is low in phosphorus, never exceeding in the massive form 0.07, and usually, in cargo-lots, running below 0.05 per cent. In the stratified form the phosphorus contents usually run a trifle higher than in the massive ore, but never exceed 0.09 per cent. The different ores will be described in more detail, and analyses given, under the descriptions of the several mines.

The Mines of the Caribbean Manganese Company.

The Soledad Mine.

This mine, the most important of the region, is about 6.5 miles in a direct line, or 9 miles by railroad, SE. of the port of Nombre De Dios. The first discovery here was of large and small boulders of manganese-ore scattered over the westerly and northerly slopes of the Soledad mountain. Large quantities of ore were in sight upon the slopes of four small streams that head upon the mountain and flow into the Mamey river, as also in the river itself where it skirts the base of the mountain. The boulders were all upon the surface, or at slight depths below. The surface-soil was yellow clay formed from the decomposition of a shale. In shallow excavations the clay became harder, and the original lines of stratification were usually visible, although the decomposition extended to a much greater depth. The boulders of manganese were invariably contained in the thoroughly decomposed surface-rock, and extended investigation failed to show any ore in the lower strata.

It was at first believed that these boulders represented distinct pockets of ore, originally contained in the shale, some being still in their original position, surrounded by the clay formed *in situ* by the decomposition of the shale, while others

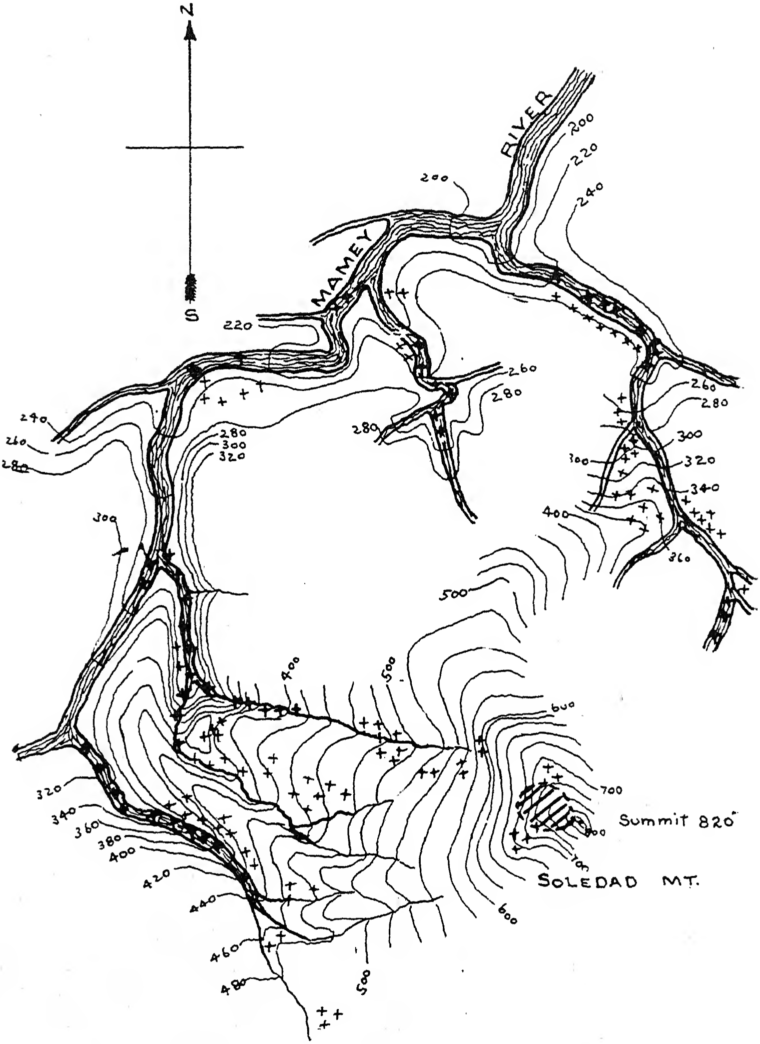
had been left exposed upon the surface by the erosion of the clay, or naturally concentrated, after such erosion, in the beds of the streams. In some portions of the Panama region, as in other manganiferous areas where the ore is found in scattered masses with no apparent source of origin, it is undoubtedly true that each boulder was originally a distinct ore-pocket in the containing rock, or, at any rate, was first contained in the rock in the remains of which it is now found. The ore comprising the boulders in these cases was probably contained in the original rock generally in small particles, and, on the decomposition of the rock, large masses were formed by the resulting ore-concentration and the action of surface-waters charged with manganese oxides and carbonates.

The difficulty of applying this theory to the Soledad boulders lay in the fact that they were all contained in the completely decomposed rock on the surface, while the same rock at a small depth contained only traces of ore. This fact, combined with confinement of the boulders within a fan-shaped area converging toward the mountain summit, and the angular form of many of them, which seemed to indicate that they had been recently broken off from larger masses, led to a thorough exploration of the upper portion of the mountain, upon the theory that the boulders were "float" from a parent deposit above. The discovery in 1896, and the subsequent development, of a large body of ore in place nearly upon the summit of the mountain, about 700 ft. above sea-level, proved the truth of this theory.

The contour-map, Fig. 3, shows the topography of the Soledad region, and the manner of occurrence both of the ore in the parent-deposit and of the float. More than 10,000 tons of high-grade ore were obtained from the scattered boulders. In one instance more than 600 tons were secured from one boulder.

At the main ore-body the accompanying rock is a decomposed shale, in many places (especially south of the body) changed to jasper. This rock is highly impregnated with oxides of iron and manganese, and also highly silicified. It varies in color from red to yellow, and shows numerous fracture-planes, often having a film of manganese oxide between two adjacent portions. It is also intersected by many small seams of quartz. When the strata are visible, they are often much disturbed and contorted, and sometimes thrown into short folds. They are gen-

Fig. 3.



MAP SHOWING TOPOGRAPHY
MANGANESE REGION, SOLEDAD MINE
SCALE 1"=600'

0 10' 20' 30' 40' 50' 60' 70' 80' 90' 100'

NOTE
CONTOUR ELEVATIONS ABOVE SEA LEVEL.
PRESENCE OF MANGANESE BOULDERS
SHOWN THUS +++
ORE IN PLACE SHOWN THUS

erally tilted from 70 to 80 deg., dipping SW. The general strike of the ore-bearing strata from the coast inland is S. 5° E. Near the Soledad mine, where the first considerable upheaval took place, the strike varies from that shown further north, the strata here following the direction of the range of foothills about S. 70° E.

The ore-bodies generally follow the bedding-planes, being occasionally interstratified with the rock, but usually constituting a series of lenticular or irregular masses, connected by small stringers of ore. A red clay, occurring in large masses within the ore-bearing area, and intimately associated with the ore, probably represents a completely decomposed rock, originally deposited with the ore. In width, the ore-bodies vary from a maximum of about 50 ft. down to a few inches. As they follow, generally, the stratification-planes, the unaltered bodies dip about 80 deg.

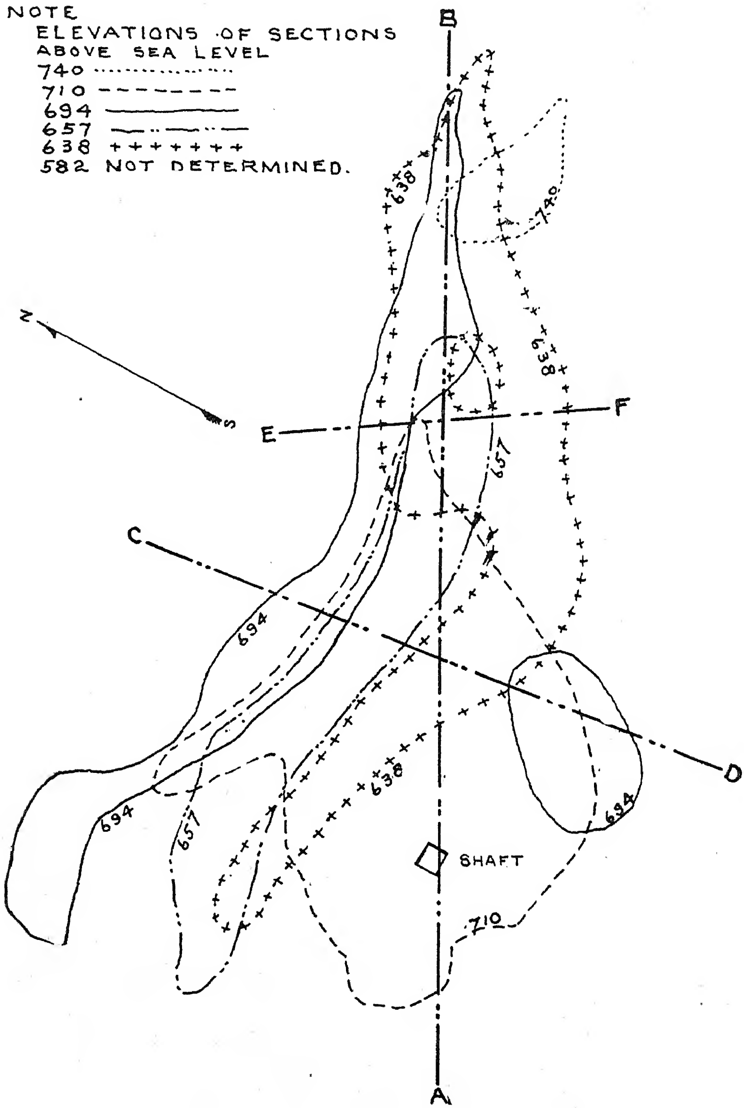
The rock on the SW., forming the so-called hanging-wall, is a highly silicified jasper, passing by blended gradations in the upper level to the original shale. On the NE. side there is usually a stratum of red clay of variable thickness in contact with the ore; and a bed of volcanic ash from 2 to 8 ft. thick is next encountered, followed by the shale.

Both the manganese-ore and the jasper show numerous fracture-planes, partly caused, no doubt, by the general upheaval of the region, but probably due, in the main, to the subsequent adjustment of the rocks, resulting from the change of volume which followed the secondary concentration and enrichment of the manganese deposit from the surrounding rock.

The Soledad ores comprise braunite, pyrolusite and psilomelane,—principally the last. The greater part of the ore is massive, varying in color from a steel-gray to a bluish black, and usually showing a conchoidal fracture. It is rarely stratified; but there are some bodies of interstratified soft ore and clay. Pockets of ore, soft enough to be mined without explosives, are occasionally, but not often, found in the massive ore.

Fig. 4 presents horizontal sections of one of the principal ore-bodies at various elevations, including (on account of the great irregularity of the ore-body) intermediate points as well as the mine-levels. Fig. 5 gives a longitudinal section of the same ore-body, and cross-sections are shown in Figs. 6 and 7;

Fig. 4.

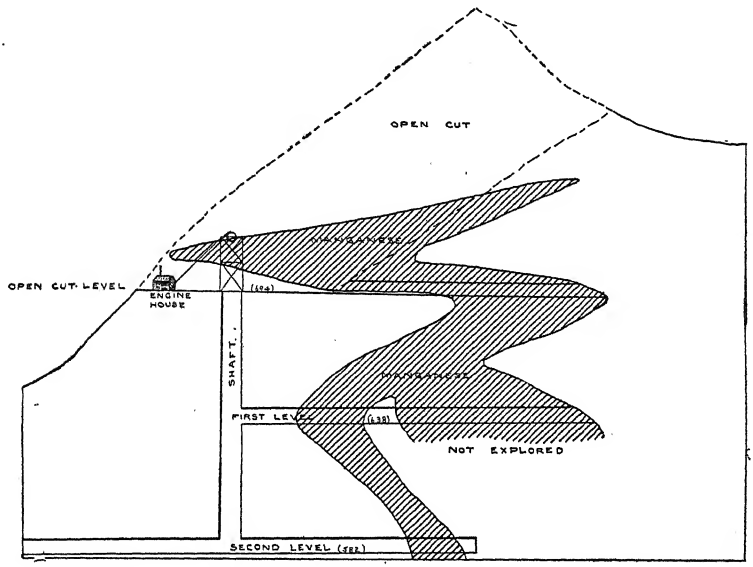


SOLEDAD MANGANESE DEPOSIT
HORIZONTAL SECTIONS
SCALE 1" = 40'

0 10 20 30 40 50

the section-planes being indicated on the plan in Fig. 4. The cross-section shown in Fig. 6 is found only near the outcrop of the ore-body; and the excess of ore in the upper portion is probably due to a secondary concentration, following weathering and partial erosion at the outcrop. A large portion of the Soledad deposit has been removed by erosion. As already observed, more than 10,000 tons of high-grade ore was mined from the float. Nearly 20,000 tons of all grades was in sight

FIG. 5.



SOLEDAD MANGANESE DEPOSIT
LONGITUDINAL SECTION ON LINE AB (SEE PLAN).
SCALE 1'' = 80'

when work began. The plan and sections shown cover only a small portion of the ore-bearing area.

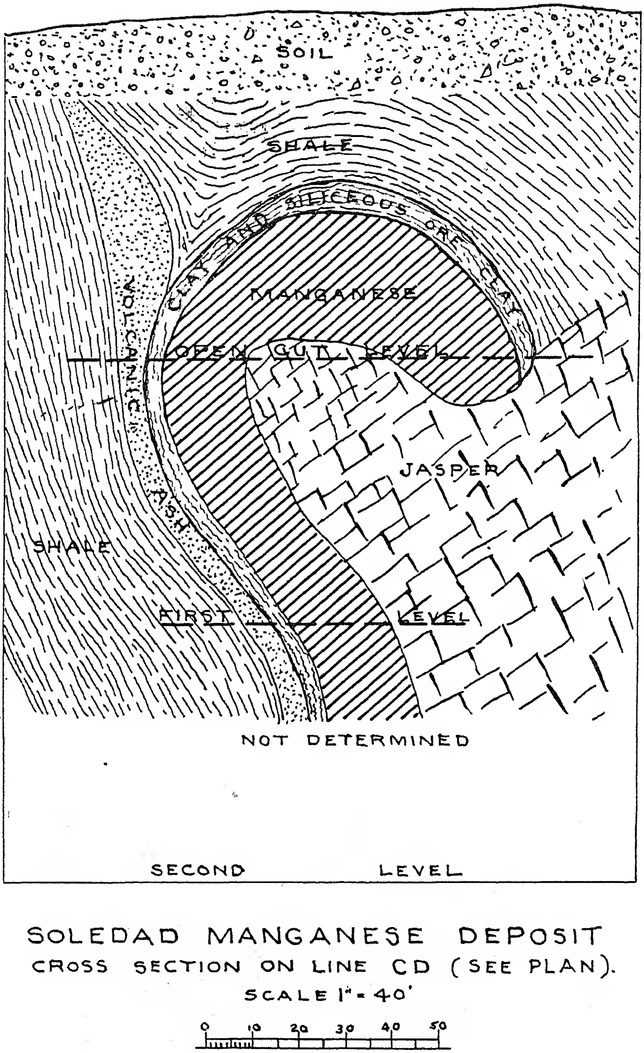
The depth to which the ore extends is unknown. It is seen continuing below the lowest level of the mine, which is about 230 ft. below the summit of the hill. Of this depth, about 110 ft. is represented by the underground workings, and about 120 ft. by an open cut.

About 30,000 tons have been mined from the ore in place. This does not include the ore mined from the boulders on the slopes of the hill, which were originally included in the de-

posit. Including the surface-boulders, upwards of 40,000 tons has been furnished by this ore-body.

The best cargo-lot ever shipped from this property was one

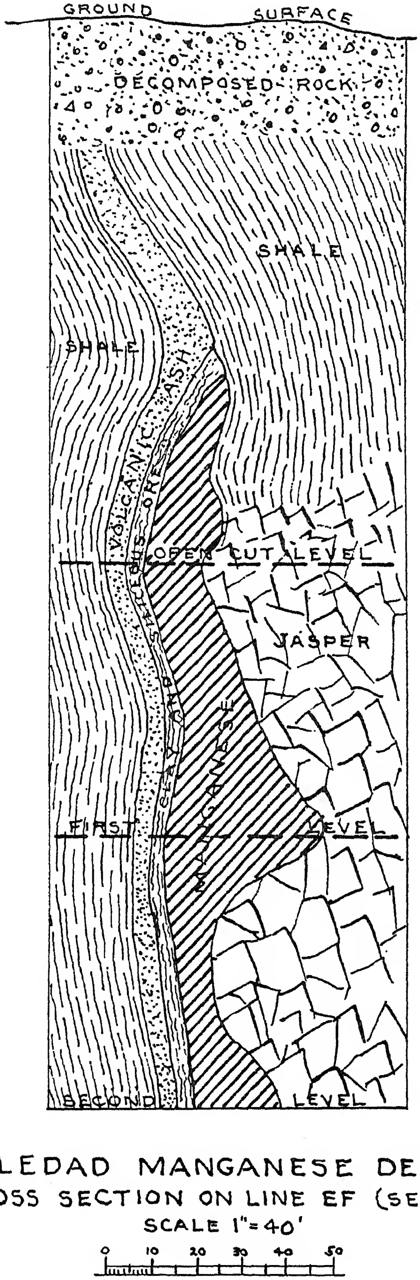
FIG. 6.



SOLEDAD MANGANESE DEPOSIT
CROSS SECTION ON LINE CD (SEE PLAN).
SCALE 1" = 40'

of about 1500 tons, which contained, according to sample-analysis, metallic manganese, 57.50; silica, 4.18; and moisture, 2.73 per cent.

Fig. 7.



SOLEDAD MANGANESE DEPOSIT
CROSS SECTION ON LINE EF (SEE PLAN)
SCALE 1" = 40'

Other large lots, of equal grade within fractional percentages, have been shipped. Of the total of more than 40,000 tons shipped from this property, complete analyses are not at hand; but the average analysis of about 23,000 tons was: metallic manganese, 53.74; silica, 8.68; and phosphorus less than 0.06 per cent.

This fairly represents the high-grade ore in cargo-lots. No washing or other preparation is necessary for the best lump ore. It is shipped as it comes from the mine, except that it is hand-picked, to remove the siliceous pieces. The fine ore requires washing.

Besides the high-grade bodies, there are large bodies of siliceous ore carrying about 47 per cent. of manganese, and from 18 to 30 per cent. of silica. These are not worked at present, but will undoubtedly be utilized hereafter, since the greater part of the silica is not in chemical combination with the ore, and can be removed by crushing and jigging. The percentage of phosphorus in these siliceous ores is always under 0.075.

Method of Mining.—The discovery outcrop is about 100 ft. below the summit of the hill. An open cut was begun about 20 ft. below the outcrop and carried in until the walls were 100 ft. high. The mountain, rising faster than the ore-body, gave a constantly increasing over-burden to remove; and this, with the difficulty of holding the side-walls, led to the abandonment of open-cut work and the beginning of underground mining in 1898. A tunnel was driven into the ore-body from the open-cut level. From the same level a shaft was sunk 110 ft. and two levels were opened. The mine is drained by a tunnel on the bottom level connecting with the shaft.

The ore is usually stoped for the entire width of the deposit, both heavy timbering and supplementary filling being required. At some points it is necessary to leave pillars of ore in place, to be extracted when the stope is about to be finally abandoned. The ground is difficult to hold, because of the decomposed rocks surrounding the ore and the large masses of clay associated with it. Occasionally a pocket of clay is opened which is under heavy pressure from the surrounding rock or ore. As soon as an outlet is furnished, the clay begins to flow into the stope in a plastic mass; and great difficulty is often experienced in checking this flow. The most satisfactory method of work-

ing—indeed, the only one by which the soft clay walls can be held—is to keep the stopes filled to within about 7 ft. of the roof. The ore-shoots and man-ways are built up from the level below, as the filling is carried up. The material for filling, apart from what is furnished from waste in the mine, is obtained outside, on the open-cut level.

Square-set timbering has been used in large stopes, but it has been found better and cheaper, where the filling system was employed, to support the roof with cribs of round logs, which accommodate themselves, without damage, to the shrinkage of the newly-filled material and the pressure from the ore.

The ore from the lower levels is hoisted to the open-cut level by a gasoline hoist, which was installed on account of the difficulty of obtaining a supply of water through the dry season.

The ore is hand-picked on the open-cut level, the large pieces going direct to the tramway which connects the mine with the railroad, while the small pieces and finely-powdered ore are transported separately, taken to the log washer, and screened after washing.

The size above 0.5-in. mesh is hand-picked and shipped; the finer portion being reserved until a suitable concentrating-plant shall have been erected. This care in sorting the ore is rendered necessary by the presence of particles of jasper in the ore, which, if not removed, subject the ore to a penalty for silica.

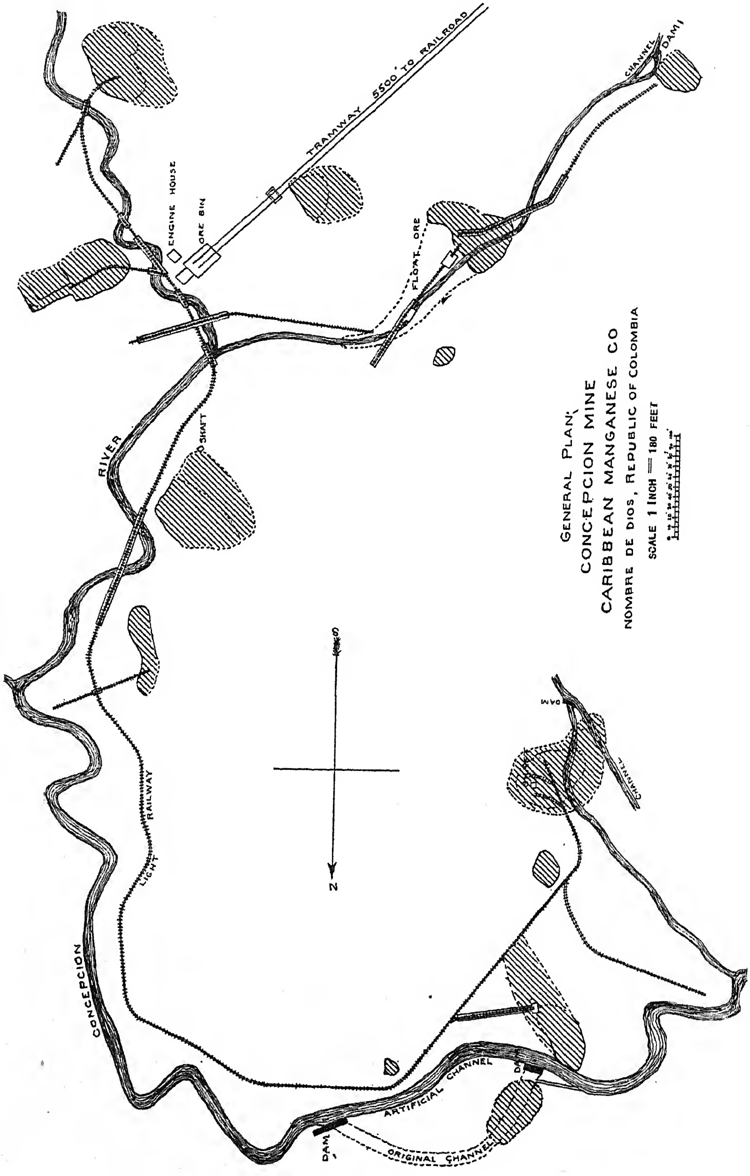
The ore is stored on the upper level in a 50-ton bin at the loading terminal of a Bleichert tramway. This tramway, about one-third of a mile in length, has its upper terminal 420 ft. above the railroad to which it conveys the ore. At the railroad there is a 300-ton ore-bin, from which the railroad cars are loaded. The tramway is operated by gravity, the descending loaded buckets developing 6 H.P. All mine-supplies, timber, etc., are brought up to the mine on the tramway, which has a capacity of 25 tons per hour.

Hand-drilling was used until the present year, when, on account of the difficulty of obtaining laborers during the revolution in the country, an air-compressor was installed, driven by a 35-H.P. gasoline-engine, and power-drills are now used.

The Concepcion Mine.

The Concepcion mine of the Caribbean Manganese Co. is about 2 m. north of the Soledad. The ore at this point

Fig. 8.


General Plan
Concepcion Mine
Caribbean Manganese Co
Nombre de Dios, Republic of Colombia
Scale 1 Inch = 180 Feet
Tramway 5500' to Railroad
Engine House
Ore Bin
Float Ore
Channel
Dam I
River
Shaft
Light Railway
Concepcion
Artificial Channel
Original Channel
Dam
N

was first discovered as boulders in the bed of a small stream flowing into the Concepcion river. A little development showed the boulders to be close to the original body from which they had been derived, the stream having cut through the ore-deposit. Prospecting in the vicinity led to the discovery of other ore-bodies in place, until, within an area of 1100 by 600 ft., more than a dozen distinct ore-deposits had been found. The map, Fig. 8, shows their relative position. About 12,000 tons has been mined here; the largest ore-body furnishing about 4000 tons.

The ore is associated with a decomposed sedimentary rock, either interstratified with it, or following, as a series of irregular bodies, the general direction of the bedding-planes. The rock is of the same general character as that surrounding the Soledad ore-deposit, except that it shows little evidence of metamorphic action. The strata are upturned at angles of from 30 to 60 deg., and the strike is about S. 3° E.

The ore is usually somewhat lower in grade than the Soledad ore, although, in one of the deposits, more crystallized pyrolusite is found. In most cases the ore is plainly stratified, nearly black in color, and much softer than the massive ore of the region. There is often a narrow seam of clay between two strata of ore. On account of the clay in the ore, the greater part requires washing.

The ore-deposits often have the general mushroom shape, shown in vertical section by Fig. 9. This is caused by the weathering of the upper portions of the upturned strata, the manganese being broken up and redeposited over a considerable area, while the stratum of ore lower down retains its original position in the enclosing rock.

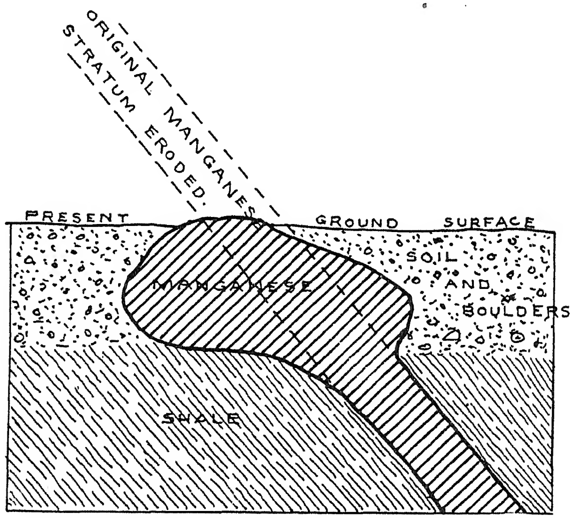
The ore is worked both by open-cuts and underground, but none of the workings have reached the depth of 100 ft. The lowest workings are below the bed of the Concepcion river, and there is considerable water to handle. A steam-pump and two hoisting-machines are in operation.

The mine is connected with the railroad by a Bleichert tramway 5600 ft. long, with a carrying-capacity of 15 tons per hour. The terminals are at nearly the same level, and the tramway is operated by a steam-engine of 10 H.P., located at the discharging terminal. The various workings of the mine are connected

with the tramway by a portable railroad-line of 0.5 meter gauge. The ore is hoisted from the pits in buckets holding about one ton each, which are placed upon cars and hauled to the tramway-terminal, where the ore is hoisted and dumped into a 50-ton bin, from which the tramway-buckets are loaded.

The log washer, which serves both mines, is located at the

FIG. 9.



SECTION OF ORE DEPOSIT
CONCEPCION MINE
SHOWING CONCENTRATION OF ORE BY EROSION
SCALE 1" = 40'

discharge-terminal of this tramway. The ore which requires washing is here washed, and then taken to the shipping-port. No screening of the small sizes is necessary, as at the Soledad mine, since the only impurity is a soft clay, which is easily removed by washing.

Analyses of Ore.—Samples of ore from different deposits on the property gave the following analyses:

	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.	Per Cent.
Metallic manganese, .	46.97	54.82	52.58	50.70	52.30	55.69
Iron, ...	1.24	1.45	......	......	......	2.59
Silica, ...	8.89	8.55	0.80	6.44	0.64	0.82
Phosphorus, . . .	0.083	0.087	0.068	0.045	0.030	0.045
Lime, ...	1.60	1.28	1.43	1.67	......	......

The analysis in the last column is that of a selected specimen.

Washed ore in cargo-lots will average nearly 50 per cent. of manganese and about 8 per cent. of silica. In cargo-lots, without washing, the ore contains enough clay to reduce the manganese contents to 44 per cent. and increase the silica to 12 or 14 per cent.

Transportation and Shipping.—From the bins at the railroad the ore is loaded by gravity into small side-dumping cars, of about 3 tons' capacity, and hauled to the shipping-port. Here it is dumped from a trestle upon the stock-pile. There is storage here, without rehandling, for about 3000 tons. The ore is shipped in steamers which are loaded alongside the Company's wharf. It is loaded into tubs, holding about 1800 lbs. each, which rest on small trucks running on a track of 0.5 meter gauge. There are two endless tracks, one on each side of the ore-pile, extending onto the wharf. The ore-trucks make a continuous circuit, the loaded tubs being hoisted and their contents dumped into the steamer's hold, and replaced empty upon the truck, which then returns to the ore-pile to reload. Each track serves a separate hatch on the steamer; and the ore is loaded at the rate of 400 tons or more daily.

The Carano Mine.

The Carano mine of the Caribbean Manganese Co. is about 1 m. north of the Concepcion, and about 2 m. from the coast. The geological formation here is similar to that at the Concepcion mine, and a number of ore-deposits in place have been partially developed. Some of these would yield a considerable tonnage. The ore is usually stratified, and the deposits lie in bodies parallel to the bedding-planes of the rock, except where they have been concentrated on the surface by erosion and weathering. The strike and dip of the stratified rocks is the same as at the Concepcion.

About 200 tons of ore was mined here in 1892, and transported to the coast on pack-mules; but lack of transportation facilities have prevented any extensive operations since.

The ore is of the same general character and grade as that of the Concepcion mine.

Viento Frio Mine.

This mine, belonging to the Caribbean Manganese Co., is about 1.25 m. north of the Carano, and near the coast. No large ore-deposits in place have been found at this point, as at the mines previously described. The ore occurs as boulders in a stiff clay, varying in color from red to white. The country is comparatively level; and these boulders are probably the remnants of a stratified deposit obliterated in the wearing down of the surface.

As some of the boulders show a stratified structure, and as their location is directly upon the strike of the formation produced north from the Carano mine, it is probable that they are the remains of an ore-deposit similar to those previously described. It is, of course, possible that the boulders were originally contained, largely in their present form, in the rock from whose decomposition the clay was derived; but the history of the other deposits of the region and the stratified form of the boulders make the first supposition more probable.

About 1500 tons has been mined at this point, the greater part between 1870 and 1873 by the early miners, and the rest since the acquisition of the property by the Caribbean Manganese Co. The ore is similar to the Carano and Concepcion ores. Here, as at the Carano mine, lack of transportation facilities has prevented any extensive work.

Mines of Messrs. Brandon, Arias and Filippi.

La Guaca Mine.

La Guaca mine, of Brandon, Arias and Filippi, is about 2 miles northwesterly from the Soledad mine.

The ore occurs in large and in small boulders originally exposed in the beds of the streams and upon the adjacent slopes of the mountains.

About 1000 tons of high-grade ore was obtained from one

boulder at this point. The original source from which the ore was derived is not known. It is, of course, possible that the boulders represent small deposits of ore exposed by the decomposition and erosion of the surrounding rock.

The rocks associated with the ore are the same as at the Soledad mine; and it seems most probable from the history of other deposits in the region, and the close resemblance in the geological structure and character of the ore, that the boulders are float from some large deposit upon the mountain as yet undiscovered; or possibly the parent deposit may have been entirely eroded, leaving only the boulders to bear evidence to its existence. The heavy clay mantle which covers the country makes prospecting very difficult and expensive.

The ore at this point is of high grade and closely resembles the Soledad ore, being very hard and steel-gray to black in color, with a conchoidal fracture.

A portable railroad of 0.5 meter gauge, about half a mile in length, connects the mine with the railroad.

About 2000 tons has been mined at this point.

Culebra Mine.

All the mines previously described are adjacent to the railroad of the Caribbean Manganese Company. The Culebra is situated upon a small island, about 14 m. east of Nombre De Dios, and half a mile from the mainland, opposite the village of Culebra. The island rises abruptly from about five fathoms of water, and its highest point is about 40 ft. above sea-level. It is about 200 ft. long and 150 ft. wide, the direction of the longer axis being NNE. and SSW.

Apart from the ore-body, the island is composed of the metamorphosed sedimentary rock previously described as jasper in the Soledad mine. The strata are tilted at an angle of about 80 deg., which corresponds with the dip of the ore-formation at the Soledad mine, and the strike is approximately NNE. and SSW., corresponding to the longer axis of the island, and only varying about 20 deg. from the strike of the ore-formation in the mines to the west.

The manganese-bearing strata are said to be about 80 ft. thick; and the ore occurs in lenticular or irregular bodies along the bedding-planes. One body of large size has been worked

in an open pit, 60 by 45 ft. in area, which was carried 15 ft. below sea-level; the ore extending into the sea, and a rim of ore being left in place as a sea-wall. During the prevalence of the NE. trade-winds, great difficulty was experienced in working, on account of the heavy seas breaking over the sea-wall and flooding the pit. A shaft is now being sunk from the highest point of the island, and has been carried to a depth of 47 ft. below sea-level. The open workings have been abandoned.

Ore has been found by borings under the sea upon the direction of the strike about 150 ft. from the island, and is also found upon the mainland about 2 miles SSW. from the island, in the direction of the strike.

The ore is usually hard, although bodies of soft ore are occasionally found. The greater part of the ore is a hard black or steel-gray ore closely resembling that at the Soledad mine. It is chiefly psilomelane and pyrolusite, and of high grade.

Both the ore-deposits at this point and the associated rocks are similar to those occurring in the mines to the west, the dip and strike of the formation closely corresponding.

It is therefore probable that they were formed in a similar manner and represent a parallel formation.

About 4000 tons of high-grade ore has been produced here.

The ore is loaded directly into steamers from a wharf built out for a short distance from the island.

The writer is indebted to Mr. M. Filippi, of Brandon, Arias and Filippi, for information concerning the La Guaca and Culebra mines.

The Meamar Mine.

The Meamar mine is about 7 m. E. of Nombre De Dios, and about half a mile from the village of Meamar, or about halfway between the first series of mines described and the Culebra mine.

A small amount of work has been done here by a French company, but no ore has been shipped.

The ore is found, as at other points along the coast, in boulders in a stiff clay of varying color. Boulders of jasper are found with the ore; and the formation seems to be similar to that of the other deposits described above. A small stratified deposit has also been found, dipping at a high angle.

The ore appears to be of slightly lower grade than at any of the properties before mentioned.

About 300 tons has been mined and stored, awaiting some method of transportation to the coast.

Origin and Occurrence of the Ore-Bodies.

As already observed, the rocks associated with the ore-formation are all of sedimentary origin, and the ore-deposits are also undoubtedly a sedimentary formation. As Fig. 2 shows, the four mines of the Caribbean Manganese Company, the Viento Frio, Carano, Concepcion, and Soledad, lie approximately in a straight line, running about S. 3° E. This is also the direction of the strike of the exposed strata at the three mines nearest the sea; and the Soledad mine lies upon the same line, although the strike changes at that point, following the axis of the foothill range. It is therefore probable that, as the rocks associated with the ore are the same, these four mines are upon the same ore-bearing strata, which consist of decomposed sedimentary rocks, probably shales, though now so decomposed that their original character cannot be decided with certainty. Upon the surface over this area only the clay resulting from the rock decomposition is visible, except where the rock has been preserved by metamorphic action, but at slight depths the original bedding-planes can usually be seen. The maximum thickness of the ore-bearing formation from east to west is about 600 ft., and the strata are sharply upheaved, approaching the vertical. In the lowest workings of the Soledad mine, about 230 ft. below the surface, the ore still extends downward.

It is probable that the other mines of the region are upon parallel formations. The strike of the Culebra ore-formation, varying only about 20 deg. from that strike of the formations further west, makes this seem plausible.

The original source of the manganese was probably in the older rocks of the region. Upon the decomposition of these rocks by atmospheric influences, the manganese existing in them in the form of silicate was taken into solution by surface-waters and redeposited as a constituent of the resulting sedimentary rocks, or, where conditions were exceptionally favorable, as bodies of manganese-ore in the form of oxide or car-

bonate. The Panama deposits were probably laid down as oxides. No carbonate has been found in the region, even in the deepest workings. It is, of course, possible that ore originally deposited as a carbonate was afterwards converted to an oxide; in fact, this would probably occur in any portion of the deposit exposed to atmospheric influences. In speaking of the deposition of ore, R. A. F. Penrose says:*

"When waters containing manganiferous solutions are in rapid motion, as at the mouths of springs, or in rivers and creeks, they are freely exposed to oxidation, and, consequently, the part of the manganese that is precipitated is usually in the oxide form. The part that is not precipitated, however, is carried on to the body of water to which the streams are tributary, and there precipitated, sometimes as oxide and sometimes as carbonate. When the manganiferous solutions in the form of surface-waters are protected from oxidation by being in the presence of a reducing agent, such as veg table or animal matter, they are often precipitated as carbonate. The bicarbonate or other salts of manganese that are in solution, however, are so easily oxidized that, unless the protection from oxidation is very complete, the manganese is precipitated as oxide."

When the ore was deposited as a constituent of sedimentary rocks, subsequently upheaved and decomposed, other ore-deposits may have been formed or existing ones enriched by chemical changes or additions from mineralizing solutions, or by concentration resulting from the weathering of the upper portion of a rock containing ore, thus concentrating in one resultant body the ore originally contained in all the portion decomposed above.

The decomposition of the ore-bearing formation in the Panama region was probably hastened by the high angle at which the strata are upturned, allowing free access to surface-waters.

The result of this natural concentration on small ore-deposits, or on rocks containing ore, has often enabled the miner to work profitably the upper portion of a manganese-deposit, while his hopes were suddenly shattered when, at a small depth, the deposit converged to a narrow stratum of ore, or a mass of lean ore-bearing rock.

The manganese-deposits of the Panama region are probably of Tertiary origin, as will be shown later; and it is most probable that the deposition of ore took place in lagoons along the coast line.

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* *Annual Report of the Geological Survey of Arkansas for* 1890, vol. i., pp. 552, 553.

The geological age of the deposits and the origin of the ore have been discussed by Mr. E. J. Chibas in the paper previously referred to. The conclusions arrived at by him are substantially similar to those of the present paper, except on some points of ore-formation and occurrence depending on the existence of the large deposits in place, and the float derived from them. The existence of the deposits in place, in the Soledad mine at least, was unknown when the paper of Mr. Chibas was written.

Probably the most favorable condition that could exist for the formation of a manganese-deposit upon a large scale, where the surface-waters hold manganese in solution, would be the condition that exists to-day along the coast of the manganese-region, where many of the rivers flow into lagoons, and the waters cover a large area of shallow depth. In most of these lagoons no outlet exists to the sea. Some of the water finds its way through to the ocean by filtration, and part is evaporated. Under these conditions the solution is concentrated by evaporation; and, as the water remains in the lagoon for a long period, the oxidation and precipitation of substances held in solution is rendered possible to a greater extent than under most other conditions afforded by Nature. In addition to the metalliferous solution, the water would hold in suspension the finely-powdered insoluble portions of the disintegrated rock. If conditions were favorable for the deposition of this suspended matter at the same time with the chemical precipitation of the ore, the resulting formation would vary from a sedimentary rock containing ore to an impure ore. When, however, the conditions favored chemical precipitation only, the result would be a deposit of comparatively pure ore.

In the case under consideration, it is probable that, before the streams reached the lagoons, the greater part of the insoluble matter originally held in suspension had been deposited, and the conditions were thus more favorable for the formation of a body of pure ore than in the upper portion of the river, nearer to the disintegrated rock. It is probable, except in the case, mentioned elsewhere, of metamorphism accompanied by a high temperature (under which condition the ore would have taken up silica from the surrounding rock, and, if not converted into a manganese silicate, would yet have become so

siliceous as to be valueless as ore), that the secondary changes in the ore-deposits, after upheaval, were usually in the direction of concentration and enrichment.

The deposition of the ore as an oxide in both rivers and lagoons can be plainly seen in the region at the present day. Pebbles coated with manganese oxide can be found in rivers near the ore-formation. In some places the bed-rock of a stream is covered with a stratum of oxide an inch or more in thickness. In prospecting, it is sometimes necessary to break the loose rocks in the beds of the streams with a hammer, as all have the black coating of oxide, and it is impossible to tell by inspection the manganese-pebbles from the rock-pebbles. Again, a conglomerate made by the cementing of the river-pebbles with manganese oxide is sometimes found in a stream-bed.

In the lagoons along the coast nodules of manganese are often found, in some places very abundantly; and a deposition of oxide upon a conglomerate occurring near the sea has been noticed.

The deposition of ore in this region is undoubtedly going on at the present day, precisely as in the past, though probably more slowly, because of the smaller amount of manganese in the present sedimentary rocks, and the consequent more dilute character of the metalliferous solutions.

Analyses of Rocks Associated with the Ore-Deposits.

Complete analyses of the rocks associated with the Soledad ore-bodies were made by Dr. C. H. Warren, of Yale University. The rocks are designated by the names under which their occurrence has been previously described at the Soledad mine, viz., shale, jasper and clay.

The results of the analyses were as follows:

	Shale. Per Cent.	Jasper. Per Cent.	Clay. Per Cent.
Silica (SiO_2),	74.56	90.98	49.29
Titanium dioxide (TiO_2),	0.48	Trace	1.16
Alumina (Al_2O_3),	9.09	0.90	17.58
Iron sesquioxide (Fe_2O_3),	7.45	6.58	8.42
Iron protoxide (FeO),	......	0.69	......
Manganese sesquioxide (Mn_2O_3),	1.39	0.39	3.02
Manganese protoxide (MnO),	......	0.14	0.77
Lime (CaO),	0.13	0.30	1.50

	Shale. Per Cent.	Jasper. Per Cent.	Clay. Per Cent.
Baryta (BaO),	......	......	0.67
Magnesia (MgO),	0.67	......	4.68
Potash (K_2O),	0.85	0.10	3.18
Soda (Na_2O),	0.34	0.19	1.76
Water (H_2O) at 115°,	1.96	......	3.73
Water (H_2O) above 115°,	3.20	0.21	4.90
Phosphoric acid (P_2O_5),	......	......	......
	100.12	100.48	100.66

The discussion of the analyses which follows involves the repetition of some facts and theories stated in the preceding pages, which the analytical work appears to confirm.

The rocks are, unfortunately, so decomposed as to afford little clue to their original character. From the descriptions previously given, it is evident that all are of sedimentary origin. Dr. Warren remarks, of the shale, that it is a greatly decomposed siliceous sedimentary rock, with some of the alumina probably in combination with alkalies and SiO_2 as some feldspathoid mineral, and the rest combined as a hydrous aluminum silicate. The analysis of the jasper gives no clue as to the original rock. It is strongly impregnated with iron oxide, and to a smaller extent with manganese oxide, and highly silicified. The clay, he says, as far as the analysis shows, might be the remains of either a basic, igneous, or a sedimentary rock. Some of the SiO_2 is probably in combination with the alkalies, and part of the Al_2O_3, as a feldspathoid mineral; some with Al_2O_3 and H_2O as a hydrous aluminum silicate; and some, possibly, with magnesium and water as a hydrated magnesium silicate. The clay represents in all probability a rock, now completely decomposed, originally laid down with the manganese. This is shown by its position in the ore-bodies, and is confirmed by the chemical analysis, which shows a concentration of metallic contents as the ore-body is approached. The close relation of the clay to the ore is shown by the high percentage of iron and manganese oxides contained in it, and by the presence of baryta, usually an accessory constituent of psilomelane, of which the ore-body is partly composed. Potash is also usually found in psilomelane; and the greater percentage of this in the clay than in the other rocks is noticeable. Some authorities classify psilomelane as baryta-psilomelane or

potash-psilomelane, according to the predominance of the accompanying mineral. Dana says (*System of Mineralogy*) that a part of the manganese in psilomelane is replaced by barium or potassium.

It is impossible to determine from the analyses the original character of any of the three rocks; but it is probable that the shale and jasper were originally identical sedimentary rocks, and that the jasper is the metamorphosed shale. This is indicated by the physical appearance of the rocks and the blending of the jasper into the unaltered shale, both vertically and horizontally.

There was no general regional metamorphism; but during the uplifting of the country volcanic forces were active, and local metamorphism of the sedimentary rocks occurred from the effects of the eruption of igneous rocks, as well as from the general dynamic effects of the elevation of the country.

In general, the metamorphism of the rock probably caused no great change in the character of the ore. A low temperature usually accompanied the process, as is shown by the fact that the ore remained, even in contact with the metamorphosed shale, as an oxide low in silica. Under this condition, the tendency of the metamorphic action was to consolidate the ore, and convert it from the stratified to the massive form. On the contrary, where a high temperature accompanied local metamorphic action, the manganese oxide was changed to a silicate, or at least took up a large amount of silica from the rock. A good example of this is shown in one portion of a deposit in the region where it has been subjected to a high temperature from a volcanic eruption. The ore is covered by volcanic ash and fragments of lava, and has been converted into a light, scoriaceous mass, strongly impregnated with silica, while an area of surrounding shale has been converted to jasper.

A somewhat similar instance of the metamorphism of shales to jaspers in the coast ranges of California is described by G. F. Becker.*

The high silica contents of the jasper shown by the analysis are noticeable. This may possibly be due, in part (aside from the original metamorphic action), to the action of mineralizing solutions from surface-waters flowing along the steeply-

* *Geology of the Quicksilver Deposits of the Pacific Slope,* U. S. Geol. Survey, 1888.

inclined strata of the decomposing shale, and causing, after the upheaval, a secondary enrichment of the manganese deposit. To these ore-bearing solutions, the mineral contents of which were derived from the decomposition of the sedimentary rock, the jasper, by virtue of its position on the north of the deposit, and its more compact structure after metamorphism, acted as a dam, against which the deposition of ore from the solutions took place upon the existing deposit, while the rock underwent more thorough silicification. The jasper and shale can thus be considered to have been originally identical.

The clay, on the other hand, as already observed, was probably deposited simultaneously with the ore at periods or in places where the conditions favored the deposition of the insoluble suspended particles of the disintegrated original rock, instead of the chemical precipitation of the ore-bearing solutions derived from the same source.

The original of the clay would therefore have been a sedimentary rock, probably somewhat similar in character to the shale, but with a greater amount of manganese contents, due to its closer relationship to the ore. When deposited, the clay represented the insoluble constituents of the primary rock of the region, the original source of the manganese. From the breaking down of these rocks, the manganese deposits and related sedimentary rocks were formed.

Age of the Manganese Deposits.

It is believed by geologists that the Isthmus was submerged until after the close of the Paleozoic era. The Western Cordillera of the Andes, which comprises the ranges on the Isthmus, probably first appeared above the sea in the Jurassic period. Of the three branches of the Andes, the Eastern, Central and Western Cordilleras, the Central is probably the oldest. Its upheaval has been placed by J. C. F. Randolph* at the end of the Triassic or the beginning of the Jurassic era, and he considers that the Western Cordillera was elevated at some period during Jurassic or Triassic time. A slow but gradual upheaval continued; but, as late as the Cretaceous, the waters of the Atlantic and Pacific probably blended in a shallow sea studded with islands.

* *Trans.*, xviii., 209.

Prof. J. D. Dana says, in his *Manual of Geology*, that a shallow water-connection across the Isthmus probably existed as late as the Cretaceous, as has been inferred from the parallel series of representative species now existing on the two sides.

At the close of the Cretaceous, Hermann Karsten* considers that the Western Cordillera had only the summits of its peaks above the sea, as a chain of islands. In his geological map of Colombia, Karsten shows the Isthmus in the immediate Panama region, as in the area covered by the manganese-deposits, as entirely of Tertiary and Quaternary formation, with numerous small isolated areas of igneous rock, the result of eruptions through the stratified deposits. He describes the region as dotted with numerous cones of dolerite, trachyte and basalt, associated with tuffs and a volcanic conglomerate—the igneous rocks occurring in a Tertiary shell-breccia, and in sandstone of the same geological period.

The elevation of the country extended throughout the entire Tertiary period; and it is believed by some geologists that slight additions to the land-area were made during the Quaternary.

The manganese-deposits, which are considered to have been formed in lagoons along the coast, were, if the theory is correct, laid down along the coast-line of the Tertiary sea, and subsequently upheaved in the general elevation of the country. In fact, whether deposited as suggested or not, it is difficult to place them elsewhere than in the Tertiary period.

Many of the present workable deposits were probably enriched during the present geological age by chemical changes and processes of secondary concentration previously discussed.

No fossils have been found in any of the workings, and it is therefore not possible to confirm any theory of the period of their formation by paleontological evidence.

Climate and Rainfall.

The heat-equator or line of maximum temperature intersects the Isthmus of Panama at about 8 deg. N. latitude. The average daily temperatures are high, and there is but little variation in temperature throughout the year.

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* *Géologie de l'ancienne Colombie Bolivarienne, etc.*

Records kept for two years at the Soledad mine, about 700 ft. above sea-level, show the average of the maximum daily temperatures for that period to be about 87 deg., and the minimum daily average to be between 72 and 73 deg. The temperature at the coast probably ranges from 2 to 3 deg. higher than this. The highest monthly average of maximum daily temperatures recorded at the mine was 90 deg.; the lowest monthly average of minimum daily temperatures was between 71 and 72 deg. The heat is rendered more oppressive by the excessive humidity. For the period under consideration no hygrometer-reading was taken showing less than 83 per cent. of humidity. The average daily humidity recorded was 89 per cent.

The rainfall is very high, probably averaging at the mines about 175 in. annually. Records for two years at the Soledad mine gave an annual fall of 175.08 in. Nearly all of the rain falls in the nine months of the wet season. The dry season usually extends from January 15 to April 15, and in this period very little rain falls.

The greatest monthly fall recorded was about 35 in. The greatest rainfall recorded in 24 hours was 15.49 in. During this deluge 8.84 in. fell in the first 5 hours, and 14.85 in. the first 11.5 hours.

The average of the maximum daily fall each month for the two years is 3.06 in. The greatest intensity of fall recorded is 1 in. in 18 min., or at the rate of 3.33 in. per hour; and an actual rainfall of 3 in. in 1 hour has been noted.

The rainfall at the coast is somewhat less than at the mines, the greater precipitation occurring on the first range of foothills. This heavy rainfall has had a great effect, during the present geological period, in moulding the topography of the country.

The Panama climate has a bad reputation abroad, which is not wholly deserved. Yellow fever is unknown in the country districts. A malarial fever is common along the coast, but it rarely assumes a dangerous form. A person living in a settled district, where good food and shelter are obtainable, should have no difficulty, with an occasional trip to a cooler climate, in preserving his health. An engineer's work usually calls him to the wilder parts of the country, where he has to endure many

hardships; and even in the settled portions, his position usually calls for greater exposure to the climate and its enervating effects than falls to the lot of those engaged in mercantile life in the towns. Even under these unfavorable conditions, men of good constitution, who observe the proper laws of living, find no great difficulty in keeping in good physical condition.

Timber-Supply.

The country is covered with a dense forest, but most of the trees are of soft woods, of little durability, and altogether unsuitable for building-purposes or mine-timbers. Mine-, bridge- and wharf-timbers, railroad-ties, etc., are all cut in the country, but only the heavier and harder growths are used. The most desirable woods for general work, aside from piles in salt water exposed to the *teredo*, have been found to be *nispero*, a hard red-wood of great durability, and *coutaro* and black *guiacan*, varieties of *lignum vitæ*. These woods all sink in water, and are so hard that a nail cannot be driven into them. All the holes for the spikes in railroad-ties have to be bored with an auger of slightly smaller diameter than the spike. No wood in the country fit to use for a railroad-tie, into which a spike can be driven, is known to the writer.

In wharf-work in salt water the hardest and most compact woods are riddled by the *teredo* more quickly than the softer varieties, unless they possess some essential quality of bitterness, or astringency, that causes the *teredo* to avoid them. It has been found by experience in this latitude that it is a waste of money to select valuable woods for piles, as they are destroyed by the *teredo* long before decay attacks them. Palms, and other fibrous, loose-grained woods, survive the longest, but have not sufficient strength for heavy wharf-structures. The partial exemption of the fibrous woods is due, as shown by Mr. Charles H. Snow,* to the dislike of the *teredo* to a wood with cracks or a fibrous structure, because of the greater difficulty of keeping intact the calcareous lining-tube of the tunnel it bores. The writer tried many woods, and found two which are partially exempt, so that they can be safely counted on for a life of from 2 to 3 years, namely, the red mangrove (*mangle colorado*) and the *alcarato*. The

* *Trans. Am. Soc. C. E.*, vol. xl., p. 178, "Marine Wood-Borers."

former wood grows in lagoons and low, swampy land along the seacoast, and has highly astringent properties. The pounded bark is thrown by the natives into pools and small streams to poison fish. It is difficult to procure this timber in pieces of sufficient size and straightness for heavy piles. The *alcarato* piles are intensely bitter, and both woods appear to be shunned by the *teredo* until long immersion has extracted their astringent and bitter properties. All the other woods tested, except the palms, which are unsuitable for heavy structures, can only be counted on for a life of from six months to a year. The *Santa Maria* wood, quoted by Mr. Snow from a work of Mr. T. A. Dritton as partially exempt, has not been found to be so by the writer. The woods tested in wharf-structures exposed to the *teredo* embrace all the woods in common use in the country for structural purposes. It would appear that no native woods are sufficiently exempt to be of any great value; and it is better to import creosoted piles, or, better still, to use iron or steel piles, in a wharf designed as a permanent structure.

It is the general belief of the natives of the country that timber must be cut in the period after the full moon and before the new moon, or otherwise it will soon decay. This belief is always regarded by strangers in the country as a superstition; but experience shows it to be based on fact. With the hardest varieties of wood in use, such as black *guiacan* or *nispero*, little difference is noticed, whether the rule is kept or violated; but, with the exception of a few of the harder varieties, the woods, if cut during the waxing moon, begin to rot almost immediately, and also become infested with a borer that riddles the outer sap-wood. The fact has been noticed by many observers doing work in the country.*

Mr. Woakes advances the theory that there is a greater amount of sap present in the wood during the waxing moon, and its fermentation and decomposition hasten the decay of the wood when cut during this period. Perhaps the most striking illustration of the fact is given in the thatched-roof houses common in the country, where the thatch is composed of a species of palm-leaf. The leaves cut during the first phases of the moon become useless in fifteen days, being literally eaten

* See the paper of Ernest R. Woakes, "Modern Gold-Mining in the Darien," *Trans.*, xxix., 249.

up by worms, while the same leaves, cut during the last quarter of the moon, do good service as roofing for a year. Whatever the cause, the facts are as stated, although the writer does not expect anybody unaccustomed to the country to believe them. As an actual test is always sufficient to convince the most skeptical, he hopes, for their own sakes, if they are ever called upon to erect in this latitude timber-structures of native wood, they will make some experiments as to the influence of the time of cutting upon the durability of the wood before proceeding with their work.

Careful inspection of all timber-structures is necessary, to preserve them from destruction by the white wood-ant. If left undisturbed, these ants will soon destroy any structure, taking out almost the entire interior of a stick of timber, and leaving a shell on the outside of apparently good wood. Fortunately, they find *lignum vitæ* and *nispero* difficult boring; and, until these woods begin to soften through decay, they do not attack them beyond destroying the sap-wood.

Mining Laws and Labor-Supply.

The mining laws of Colombia are just and liberal. It is an easy matter for either a foreigner or a native to take up a mining claim upon Government land, and a complete title can be secured at a small expense.

For the last three years the country has been distracted by a revolution, and business has been greatly interrupted. In normal times the stranger will find that the establishment of any new industry will be cordially welcomed.

In the interior of the country a large part of the population are supported by the mining industry; but the natives along the coast do not take kindly to underground work, and it is usually necessary to employ laborers from the West Indies.

For any enterprise in the Department of Panama, there is usually an available supply of laborers domiciled along the line of the Panama Canal.

The Mining Industry of the Cœur d'Alenes, Idaho.

BY J. R. FINLAY, COLORADO SPRINGS, COLO.

(New York and Philadelphia Meeting, February and May, 1902.)

I. General Description.

The Cœur d'Alene silver-lead mining district of northern Idaho is probably best known to the general public as a seat of labor-troubles. So far as the writer is aware, little has been written and little is known about its geology and resources. People interested in lead-smelting are, of course, cognizant of the economic importance of the region, but they have not communicated much of their knowledge to the public.

Exact figures as to the total output of the district are not obtainable, but the following estimates, covering the entire output of the 15 years during which the mines have been operated, are believed to be approximately correct:

Group of Mines.	Product.
Wardner Group, including the Bunker Hill and Sullivan, Empire State-Idaho, Last Chance, Sierra Nevada, Cœur d'Alene Development Co., . .	$17,500,000
Cañon Creek Group, including the Gem, Frisco Consolidated, Granite, Standard, Mammoth, Hecla, Tiger-Poorman, Custer and Bell, ...	35,000,000
Mullan Group, including the Morning, You Like and Gold Hunter, ...	7,500,000
	$60,000,000

This output covers the period of discovery and early struggles, and several periods of stagnation caused by strikes and other serious labor-troubles. In 1900 the output of the district was fully $10,000,000, and this figure would have been considerably increased in 1901 had not a curtailment of production been forced by the condition of the lead-market. In 1901 the product was about 150,000 tons of concentrates, with a gross value of $8,250,000.

The accompanying map (Fig. 1) shows the principal mining claims in this region. The numbers on the map indicate the locations, as follows:

1. Manila.
2. Sunny.
3. O. K. Western.
4. Whippoorwill.
5. Mabel.
6. O. K.
7. Johnny.
8. Danish.
9. Reeves.
10. Packard.
11. Royal Knight.
12. Queen.
13. Eureka.
14. Crown Point.
15. Heary.
16. Silver King.
17. Senator Stewart.
18. Quaker.
19. Silver Casket.
20. California.
21. Idaho.
22. Legal Tender.
23. Harrison.
24. Princess.
25. Sugar.
26. Fifty-Three.
27. Florence.
28. No. Five.
29. No. One.
30. No. Two.
31. No. Three.
32. No. Four.
33. Ontario.
34. Ontario Fraction.
35. Carbonate.
36. Sierra Nevada.
37. Tip Top.
38. Apex.
39. Rambler.
40. Oakland.
41. Excelsior.
42. Cariboo.
43. Good Luck.
44. Butte.
45. Hard-Cash.
46. Hamilton Fraction.
47. Hamilton.
48. Nevada.
49. Link.
50. Arizona.
51. Viola.
52. San Carlos.
53. Likely.
54. Skookum.
55. Jersey Fraction.
56. McLellan.
57. Lilly May.
58. Deadwood.
59. Sought Again.
60. Coxey.
61. Debs.
62. Carter.
63. Josie.
64. Allie.
65. Jack Ass.
66. Sold Again.
67. Kirby.
68. Shoshone.
69. Summit.
70. Miles.
71. Teddy.
72. Republican.
73. Tyler.
74. King.
75. Pitt.
76. Cheyenne.
77. Wasp.
78. Wheel Barrow.
79. New Era.
80. Bee.
81. Hornet.
82. Hawk.
83. Caledonia.
84. O'Connor.
85. Omaha.
86. Scorpion.
87. Oregon.
88. Combination.
89. Holman.
90. Butler.
91. Kaintuck.
92. Dakota.
93. Capetown.
94. Emma & Last Chance Mines.
95. Puritan.
96. Idaho.
97. Utah.
98. Last Chance.
99. Sampson.
100. Helen Mar.
101. Stem Winder.
102. Emma.
103. Kruger.
104. Cuban Mines.
105. Silver.
106. Johannesburg.
107. Forest Belle.
108. Bunker Hill Mines.
109. Bunker Hill.
110. Important.
111. Phil. Sheridan.
112. Chestnut.
113. Ivanhoe Fraction (?).
114. Blue Bird.
115. Geyser (?).
116. Susie.
117. Maple.
118. Rookery.
119. Homestake.
120. Butternut.
121. African Reef.
122. Mary.
123. Beulah.
124. Zululand.
125. Matabela-land.
126. Stopping.
127. Buckeye.
128. Reed.
129. Sullivan.
130. Small Hopes.
131. Lackawanna.
132. Alla.
133. Mashonaland.
134. Mabundaland.
135. No Name.
136. Miners Delight.
137. East.
138. Sullivan Fraction.
139. Rolling Stone.
140. Daisy.
141. Fair View.
142. Schofield.
143. Ollie McMillen.
144. Bonanza.
145. Iron Hill.
146. La Crosse.
147. Summit.
148. Justice.
149. Jessie.
150. Comstock.
151. Ophir.
152. Dandy.

153. Julia.
154. Walla Walla.
155. Midday.
156. No. 1.
157. Lucky Chance.
158. Bonnie Jean.
159. Tough Nut.
160. Iuka.
161. Milo.
162. Fannie May.
163. Protection.
164. Alhambra.
165. Dawn.
166. McKinley.
167. Monte Cristo.
168. Crescent.
169. Brile Mines.
170. Southern Cross.
171. Omega.
172. Polaris.
173. Step-and-a-Half.
174. Chester.
175. Protection.
176. Hanna.
177. McKinley.
178. Bartlett.
179. Emma Nevada.
180. Cœur d'Alene Nellie.
181. Argentine.
182. Argentine Fraction.
183. Keystone.
184. Lee.
185. Brewery Mines.
186. Brewery.
187. Electric Light Co.'s Grounds.
188. Big Medicine.
189. Union Mines.
190. Vermont.
191. Ore-Or-No-Go Mines.
192. Blue Taulk.
193. Brother.
194. Sister.
195. Oro Fino.
196. Silver Wave.
197. Sunshine Mines.
198. Black Cloud Mines.
199. Sunshine.
200. Iowa.
201. Monarch.
202. Black Cloud.
203. Pacific.
204. Ninety-Nine.
205. Contact.
206. Mountain Chief.
207. Shamrock.
208. Black Prince.
209. Divide.
210. Marietta.
211. Hornet.
212. Idaho.
213. Panhandle.
214. Ohio.
215. Bonanza.
216. Nugget Placer.
217. Johnny Placer.
218. Figard.
219. Banner.
220. Lucky Boy.
221. Iron Mask.
222. Idaho Mint.
223. Lucky Boy Fraction.
224. Yellow Jacket.
225. Free Coinage.
226. Speckled Trout.
227. Anna.
228. Topeka.
229. Pierce.
230. Mell.
231. Custer Mines.
232. Star.
233. Treasure Vault.
234. Mingo Chief.
235. Kola.
236. Belle of the West.
237. Tugela.
238. Belle Fraction.
239. Trade Dollar.
240. Granite.
241. Denver.
242. Crystal.
243. Empire State.
244. Manila.
245. Manila Fraction.
246. Old Hickory.
247. Daisy.
248. Patuxent.
249. American Eagle.
250. Eagle Fraction.
251. Bi-Metallic.
252. 16-to-1.
253. Hawaiian.
254. Ambitious.
255. Lucky Jim.
256. Yew.
257. Miller.
258. Aspen.
259. Jenkins.
260. Chilcot.
261. Rosa.
262. Rosa Fraction.
263. Mase.
264. Mascot.
265. Blarney Stone.
266. Knapp.
267. May Flower.
268. Protection.
269. Dobson Jim.
270. White Quartz.
271. Estelle.
272. Virginia Placer.
273. Idaho.
274. North Star Mines.
275. Grace.
276. Minneapolis.
277. Sunlight Placer.
278. Fidelity.
279. Cœur d'Alene Chief.
280. Morning Light.
281. Emma A.
282. Fanny Peak.
283. Faithful.
284. Hopeful.
285. Security.
286. Dorothy Hill.
287. Carlisle.
288. President.
289. Lucy.
290. Merrimac.
291. Monitor.
292. Monitor Fraction.
293. Manhattan Fraction.
294. Mountain Goat.
295. Amazon.
296. New York.
297. Staten Island.
298. Ajax.
299. Father.
300. Diamond Fraction.
301. Chloride Queen.
302. Switch Back.
303. Roy.
304. Roy Fraction.
305. Live Oak.
306. Tough Nut.
307. Colwyn.
308. Tuscumbia.
309. West.
310. Parallel.
311. Sitting Bull.
312. Silver Tip Fraction.
313. Parrot.
314. Mule Deer.
315. Silver Tip.
316. Red Dragon.
317. Sun Set.
318. Big Bug.
319. Ula.

320. Try Me.
321. Nilus.
322. Leonard.
323. Polly.
324. Tamarack.
325. Tamerlane.
326. Chesapeake.
327. Carbon.
328. Custer.
329. Pacific.
330. Timber Line.
331. Rose.
332. Diamond.
333. Green Hill.
334. Cleveland.
335. Green Hill Fraction.
336. Grey Eagle.
337. Head Light.
338. Mammoth.
339. Tariff.
340. Mammoth Fraction.
341. Little Chap.
342. Snow Line.
343. Saturday.
344. Walter McKay.
345. Bonaparte.
346. Sancho.
347. Crown Point.
348. Fairview Fraction.
349. Sherman.
350. Union Fraction.
351. Union.
352. Bengal Tiger Fraction.
353. Hidden Treasure.
354. Burke Tiger.
355. Stanley.
356. Silver Chief No. 2.
357. Wide West.
358. Shoo Fly.
359. Tiger.
360. Sheridan.
361. Bullion.
362. Galena.
363. Bullion Mines.
364. Liebes Fraction.
365. Reeves Mines.
366. Diamond Hitch.
367. Seattle.
368. Wellington.
369. Banner Fraction.
370. Banner.
371. Silver Queen.
372. Anchor.
373. Youngstown.
374. Bonanza.
375. Sandwich.
376. Sullivan.
377. Standard.
377a. Combination.
378. Gray Copper Fraction.
379. Gray Copper.
380. Crown Point.
381. Tom Reed.
382. Selkirk.
383. Akron.
384. Broad Gauge.
385. Narrow Gauge.
386. Chief.
387. Josie.
388. Gem of the Mountains.
389. San Francisco.
390. Esler.
391. Yankee Doodle.
392. Esler Fraction.
393. Apex.
394. Cape Horn.
395. Idaho.
396. Black Bear.
397. Badger.
398. Gem Fraction.
399. So Mote It Be.
400. Moon Light.
401. Grover Cleveland.
402. Black Bear Fraction.
403. Protection.
404. Queen of the Hills.
405. Grubstake.
406. Grubstake Fraction.
407. Bell.
408. Contention.
409. Bell Fraction.
410. Climax.
411. Iron Silver.
412. Josephine.
413. Tuff Nut No. 2.
414. Tuff Nut.
415. Exchequer.
416. Mountain Fraction.
417. Muulton.
418. Mountain View No. 2.
419. Mountain View.
420. Senator.
421. Senator Fraction.
422. Parrott Fraction.
423. Buffalo Fraction.
424. Denver.
425. Ore-or-No-Go.
426. Hecla.
427. Sunday.
428. Poor Man.
429. Burke.
430. Ella.
431. Fuller.
432. Protection.
433. Green Mountain.
434. Got-'em-Now.
435. Mat.
436. Parrott.
437. Sonora Mines.
438. Modock.
439. Sonora Fraction.
440. Sonora.
441. Alameda.
442. First Chance.
443. Great Hope.
444. First Chance Fraction.
445. May Flower.
446. Clark.
447. O'Neil.
447a. Columbia.
448. Mond.
449. Russell.
450. Ironside.
451. Consolidated Ext.
452. Katie May.
453. Orphan Boy.
454. Orphan Girl.
455. Muscatine Fraction.
456. Burlington.
457. Crœsus.
458. Muscatine.
459. Star.
460. Leadville Fraction.
461. Leadville.
462. Ore-or-No-Go Fraction.
463. Dipper.
464. San José.
465. Little Strike.
466. Iron Crown.
467. Iron Crown Fraction.
468. Lauren J.
469. Hickory.
470. Grouse.
471. Noon Day.
472. Morning.
473. Silver King.
474. Evening.
475. Midnight.
476. You Like.
477. Bummer.
478. Silver Queen.
479. Park.
480. Independence.
481. Fanny Gremm.
482. Still Water.
483. Lucretia.
484. Key.
485. Contact.

486. Gettysburg.
487. True Blue.
488. Buckeye.
489. War Dance.
490. Victor.
491. Lost Wonder.
492. Victor Fraction.
493. Jersey Minor.
494. Pay Master.
495. Ada.
496. Yolande.
497. Ida.
498. Clear Grit.
499. America.
500. Cuban Republic.
501. Mary Norem.
502. Commander
503. Gold Hunter.
504. Away Up.
505. Joe Dandy.
506. Enterprise.
507. Bullion.
508. Pine Tree.
509. Defiance.
510. Mullan.
511. True Blue.
512. West Mullan.
513. Midnight No. 2.
514. Hennessey Mines.
515. Ryan Mines.
516. Thos. Brenau Mines.
517. P. M. Kavana.
518. Central.
519. Cape Nome.
520. Crown Mines.
521. Morning Mines.
522. Evening Mines.
523. Hattie.
524. Klondike.
525. Snow Flake.
526. Club.
527. Gold Queen.
528. Hammerfest.
529. May Flower.
530. Cape Nome.
531. Surprise.
532. Sunshine.
533. Sunshine Fraction.
534. Gold Drop.

The central point of the district is the town of Wallace (see Fig. 10), which is reached from the east by a branch of the Northern Pacific railroad from Missoula, Mont., and from the west by a branch of the Oregon Railroad and Navigation Co.'s line from Tekoa, Wash. From Wallace to Missoula is 135, to Spokane, 129 miles.

The main feature of the topography is the low range locally termed the Cœur d'Alene mountains, which are merely the northern extremity of the Bitter Root range. The highest summits in the neighborhood of the mines scarcely exceed 6000 ft. in altitude. The mountains are rather the remnants of a deeply-eroded broad plateau than a well-defined range. The mines are all within the drainage of the South Fork of the Cœur d'Alene river. The veins have been found outcropping, at altitudes varying from 2400 ft. at the extreme west to 6000 ft. at the eastern and northern extremities, along the various streams which empty into this river. The country was once covered with a dense forest of fir, pine, cedar and tamarack. Near the mines a good deal of the original forest has been destroyed by fire or axe; but everywhere a new growth keeps the hills green.

The climate is healthful and pleasant. The residents live at an average altitude of about 3000 ft. There are no great extremes of heat or cold. The mercury rarely goes below zero F. in the winter or above 80° F. in the summer. In the valleys, the snow generally lasts from November to March; on the summits, from October to June. Violent wind-storms are un-

known. Occasional snowslides on the steep sides of the valleys have caused some interruption of travel and some loss of life. (See Fig. 20.)

The geology of the Cœur d'Alenes has never been thoroughly studied, and practically no details of it can be given. A vast formation of slates, greywackes and quartzites, thrown into east and west folds, covers the entire region. These rocks are all fine-grained, no conglomerates or even moderately coarse sandstones being seen anywhere. True vitreous quartzites are rare. The rocks in which the lead-bearing veins occur are usually light-colored, and could be best described as fine-grained greywacke, or something between slate and quartzite. There is only a mild regional metamorphism. As a rule, very little formation of new minerals has taken place in the rocks. They are generally nicely banded, though the stratification is often obscured by dynamic action. Rarely, however, is there a well-developed cleavage. The movements in the rocks have only produced a strong jointing in a direction usually parallel to the neighboring fissure-veins. This jointing is so pronounced in places as to give a schistose character to the rocks.

Igneous intrusions are rare. Only two kinds have been observed. The most important is a syenite or quartzless granite, which makes an enormous boss or dike on the ridge between Cañon and Nine Mile creeks. This mass has produced a well-marked contact-metamorphism in the slates and greywackes which surround it, and has exercised an important influence on the vein-formation of its neighborhood. The important mines on Cañon creek are all within a mile of it; and silver-lead veins of more or less value occur at intervals along its whole periphery, and even within its borders. It is well known to the miners of the country as "the granite."

At a number of places there are basic dikes, usually narrow, producing little or no metamorphism in the sedimentary rocks, dark-green in color, heavy and unaltered. Most of them are probably basalt. In some cases they cut through the lead-bearing fissures, with no effect whatever on the values or the mineralization of the veins. But in one important instance the Hecla vein follows a narrow dike of basalt for its entire length. The mineralization has taken place along the walls of the dike,

and in many places the basalt seems to have been, to some extent, actually replaced by galena.

II. Veins and Ore-Deposits.

All the ores of the region come from typical fissure-veins, in which argentiferous galena is associated with large quantities of siderite. The fissures occupy fault-planes, on which the amount of movement is indeterminate, but probably, in some cases, considerable. The fissure is usually well marked by a streak of gouge, between walls which are slickensided and often beautifully polished. As a general rule, only one principal plane of fissuring can be found in each vein. This is very apt to occur near the middle of the vein, but often forms one wall of the lode. Two defined walls, marked by planes of movement, are extremely uncommon.

The principal minerals of the lead-bearing lodes are quartz, siderite, galena, zinc-blende and pyrite. Near the surface, oxidation has produced lead carbonates, iron oxides, manganese oxides and native silver.

The minerals in some veins are scattered somewhat indiscriminately through the mineralized zone; but they are more apt to be arranged in streaks or zones parallel to the master-fissure. It is noticeable that, along the actual fissure-plane, the galena and other minerals are nearly always fine-grained, while at some distance from it they are apt to be much coarser. The probable reason is, that the movements along the fissure continued during the process of mineralization, breaking up the minerals after their deposition, and allowing the deposition of fresh material in the interstices.

In some veins the minerals are found to be well segregated in individual streaks, the argentiferous galena, for instance, forming seams containing from 60 to 80 per cent. of lead. In other veins, or even in other parts of the same vein, the various minerals are intimately mixed in the same ore-streak, greatly diminishing its value. In different mines, and even in the same mine, the proportion of silver in the galena varies greatly: say, from 0.25 to 2 oz. of silver to 1 per cent. of lead. Ordinarily this variation follows some fixed law in each deposit; but the law is seldom the same in two deposits. In some mines the silver-values increase or diminish longitudinally

along the vein; in others, they diminish proportionately with depth.

The ore-bodies occur in every conceivable position, from horizontal to vertical. Some of them are very large, containing millions of tons of concentrating-ore. Three of the most valuable deposits in the district do not reach the surface at all, their apexes lying several hundred feet below it. Two of these are, and the third is not, quite below the limits of oxidation. It does not appear that leaching by surface-waters has in many cases destroyed the lead-values, but there are instances where this has happened. The workable deposits, as mined, carry from 5 to 25 per cent. of lead. The average values for the district are perhaps 10 per cent. of lead and 7 oz. per ton of silver.

The following are descriptions of some of the typical lodes.

The Bunker Hill Lode. (See Figs. 2, 3 and 14.)

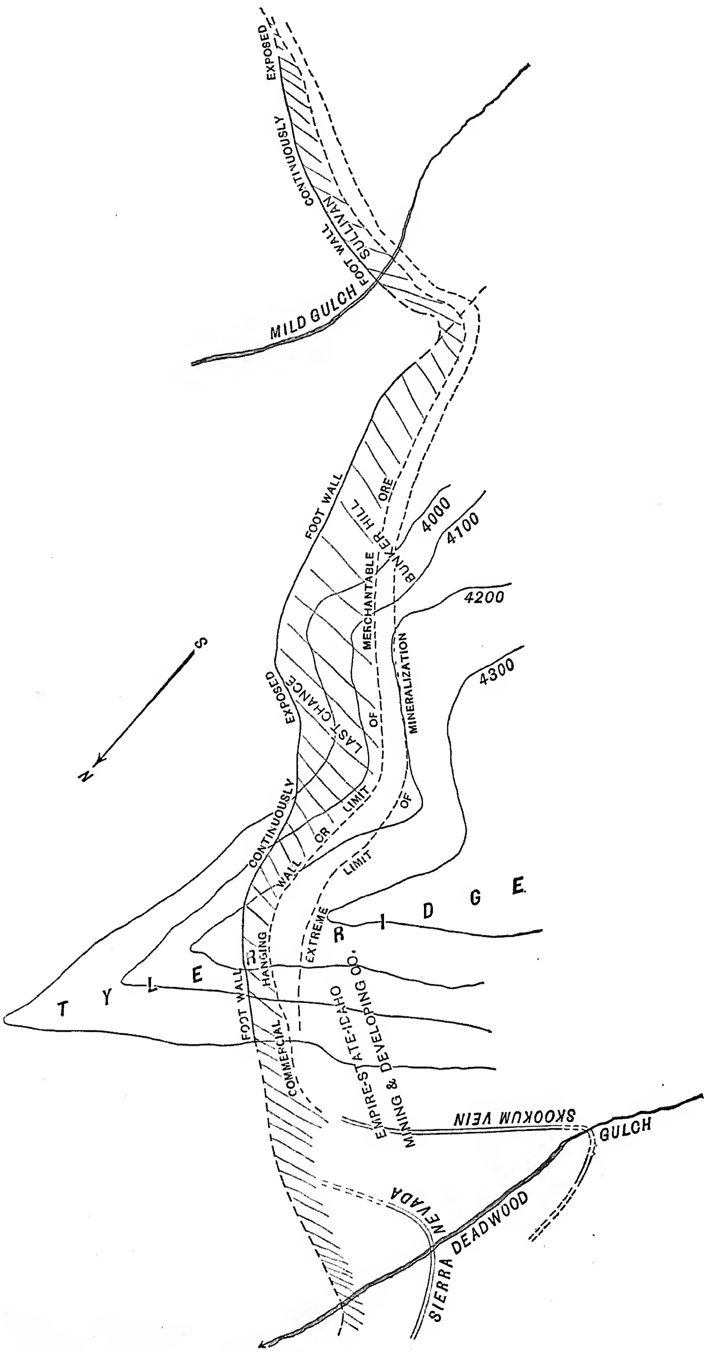
This remarkable fissure differs notably from the other veins of the Cœur d'Alenes. It seems to be the sole source of the ore in the Wardner district. For 6000 ft. from the eastern end of the workings of the Bunker Hill and Sullivan to the Viola claim of the Empire State-Idaho, the workings are continuous. From the Viola northwestward to the Crown Point the continuity of the fissure is not so clearly established; but all the ore that has been found follows the same extended line, and the workings on the Silver King and Crown Point display a fissure with the same dip, strike and general characteristics as in the Bunker Hill.

In the greater part of the course of the vein the fine-grained quartzites dip S. 60° to 70°, and strike N. 70° W.; but in places anticlines and synclines are cut through. It is quite probable that these folds are subsidiary to the grand fold of the neighborhood, but no detailed study has thus far determined this to be a fact.

The fissure strikes N. 30° W. and dips 40° SW., thus cutting the stratification at a considerable angle, both on the dip and strike,—a fact which is considered to have had a great influence on the deposition and arrangement of the ores.

It is a remarkable fact that all the mineralization has taken place on the hanging-wall side of the fissure, which therefore

FIG. 2.

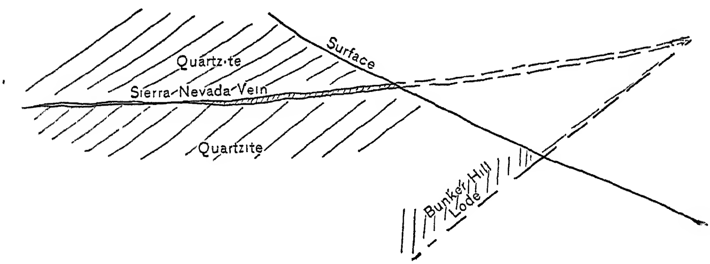


Sketch, Showing the Outcrop of the Bunker Hill Lode, as Hitherto Developed. Scale 1 in. = 1000 ft.

forms the foot-wall of the lode. A characteristic white "gouge" of thoroughly crushed and altered rock lies upon the unchanged country quartzite of the foot-wall. Lying upon this white gouge is a strongly mineralized zone, which begins with a streak of bluish or black gouge containing galena, always very fine-grained. The lamination of the rocks parallel to the fissure-plane is strongly marked for only a moderate distance (from 5 to 50 ft.) from it; but within this zone of parallel lamination the minerals, valuable or otherwise, are invariably fine-grained. The lamination in this foot-wall zone has reduced the rock to the condition of gouge-material only for a foot or two next the foot-wall.

Passing outward from the fissure, we find the mineralization

FIG. 3.



Sketch, Showing in Vertical Section the Relation of the Sierra Nevada and Bunker Hill Lode.

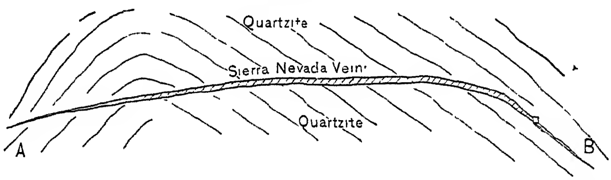
extending far into the hanging-wall, which has undergone much fracturing. For from 100 to 300 ft. from the fissure, the joints and seams in the quartzite are apt to be filled with galena, with subsidiary quartz and iron carbonate. Further from the foot-wall, the quartz, siderite and pyrite predominate, to the final exclusion of the galena. These minerals give the rocks towards the hanging-wall a silicified appearance; and in the outer zone of mineralization they make the rock much harder than the country-rock of the hanging-wall or the vein itself, nearer the foot-wall, and sometimes the lode forms great bluffs. For this reason, the prominent outcrops represent this portion of it.

The quartz, siderite and pyrite in their turn diminish in amount until at, usually, not more than 400 ft. from the foot-

wall, all mineralization has disappeared, and the country quartzite of the hanging-wall resumes the appearance of the foot-wall quartzite.

The workable ore-bodies in the Bunker Hill lode are simply those portions which contain enough galena to pay for working. Ordinarily, such bodies lie partly in the laminated zone next to the foot-wall or fissure, and partly in the fractured rock in immediate contact with this zone, on the hanging-wall. In almost every case, ore-bodies appearing in some places to be at a considerable distance from the foot-wall have been found, when followed up, to connect with it. There are, however, three conspicuous ore-bodies, the "workable" connection of which with the foot-wall has never been established. Two of these (the Curtis-Hatton body in the Bunker Hill, and the hanging-wall stopes in the Last Chance claim) seem to follow

FIG. 4.



Sketch, Showing the Sierra Nevada Vein in Longitudinal Vertical Section.

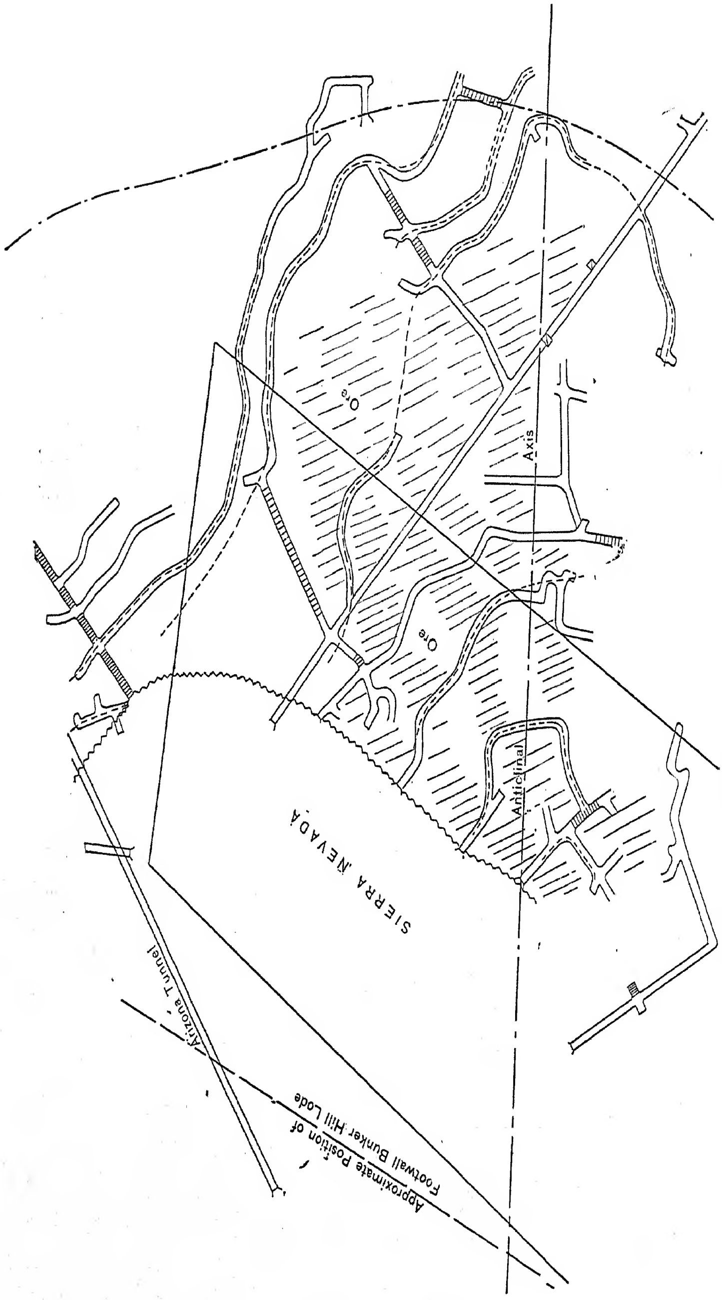
channels made in some way by the fracturing of the hanging-wall in a course essentially parallel to the foot-wall, but at some distance from it; and the third, the Sierra Nevada deposit, is a unique occurrence, which merits a more extended description.

As a general fact, however, it may be declared that the main foot-wall fissure was the source of all the mineral deposition along the lode; that the ore-bearing solutions have enriched portions of the hanging-wall country wherever a favorable channel existed; and that these channels may have been cross-fractures or local branch-fissures, regions of extensive crevice openings due to jointing, or openings along the bedding-planes of the rocks.

The Sierra Nevada Lode. (See Figs. 3, 4 and 5.)

This is a peculiar and highly specialized example of a branch-vein. It is a fissure with the shape of a broad anticline

FIG. 5.



Plan, Showing Workings of the Sierra Nevada Mine, Idaho.

which dips very gently SW., nearly at right-angles to the strike of the great fissure. The actual intersection of this anticlinal deposit (which would be termed in Australia a "saddle-reef") with the fissure has been destroyed by the erosion of Deadwood gulch; but the deposit obeys in a general way the rule governing the other deposits along the Bunker Hill lode. From a point on the surface on the crest of the anticline, nearest the line of the main fissure, it slopes gently away down the crest and sides of the anticline, and, as it does so, it loses its ore, becomes more quartzose and ferruginous until, as in other deposits, nothing remains in it but quartz and iron.

This remarkable deposit, covering an area of 6 acres, has been worked out. The old mine-levels show the contours of the anticline. The ore was all oxidized, rich in silver, and from 6 in. to 6 ft. thick.

The Canyon Creek Lodes.

These are very different from the Bunker Hill. The fissures are much smaller, simpler, and more uniform. They are nearly vertical, rarely dipping less than 75° N. or S.

The Mammoth-Standard Vein. (See Figs. 6, 7, 16 and 17.)

This important lode has produced lead and silver of the gross value of about $11,000,000, yielding at least $3,000,000 in dividends. It has been traced from the W. end-line of the Mammoth claim eastward to about 900 ft. E. of the line between the Mammoth and the Standard, at which point it has been cut off by a considerable fault, and the continuation has not yet been found. The lode has proved productive for a length of 2400 ft; and, by a curious coincidence, its richness seems to increase until its abrupt termination by the fault-plane above-mentioned. (See Fig. 6.)

The fissure strikes N. 65° W. (true), and dips about 77° N. The quartzites along the fissure dip W. at a moderate angle, so that the vein cuts the formation nearly at right angles.

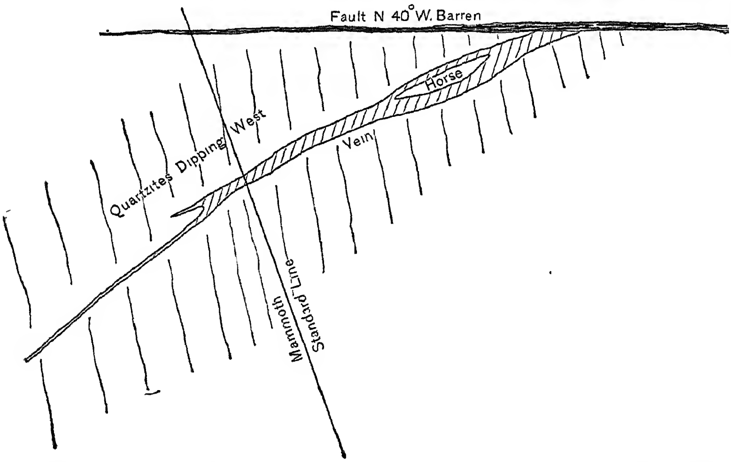
The fissure is a fault of moderate displacement. A well-defined plane of movement can always be found in the vein, sometimes on one side, sometimes on the other, and often in the middle. As in the Bunker Hill lode, the ore immediately next the fissure shows a finer grain than that deposited further away.

Fig. 7 shows the arrangement of the ore-bodies on the Standard and Mammoth, as developed on the Campbell tunnel-level.

In the Standard mine, the vein has always two, and often three or more, well-marked ore-streaks; but west of the Standard ore-shoot there is seldom or never more than a single streak.

The ore-body mined on the Standard varies from 5 to 50 ft., and averages about 17 ft., in width. There are no defined lode-walls, the fissure invariably lying within the mineralized zone, and the mineralization having affected the sheared rocks on either side. As a general rule, the rock on each side of the ore-body is sheared and crushed, for 3 ft. or more from the outermost ore-streaks, to such a degree as to render the ground somewhat loose and unstable. Beyond the limit of the sheared zone the country-rock is firm and unaltered except where it is affected by transverse faults. The parallel zones of sheared rock on each side of the ore make the walls very heavy and practically impossible to hold by timbering.

Fig. 6.



Sketch-Plan of the Mammoth-Standard Vein, and the Fault in the Standard Ground.

The Frisco Lode.

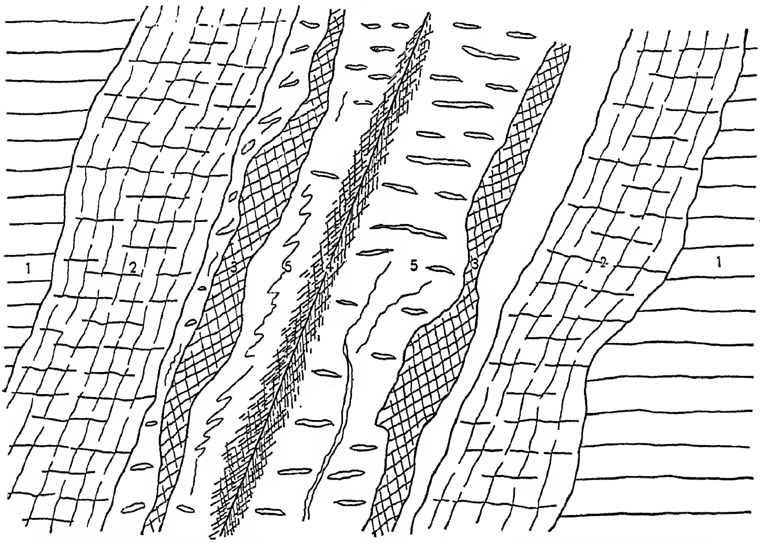
This interesting deposit has been disturbed by a number of cross-faults. The fissure proper is nowhere well marked, but the whole mass is firmly cemented together and the mineral is "frozen" to the walls.

Methods of Operation.

The mining industry of the Cœur d'Alenes may be considered under three heads: (1) The extraction of the ore from the ground, or actual mining; (2) the concentration or milling, which, at every property in the district, with two exceptions, includes transportation of several miles from mine to mill; and (3) the shipment and sale of the concentrated ore.

In general terms, there is a loss in concentration of from 20

Fig. 7.



Cross-Section, Showing Structure of Ore-Bodies in the Shear-Zone of the Standard and Mammoth.

1. Country-rock; 2. Sheared rock outside of ore-body; 3. Parallel streaks of coarse galena and iron carbonate; 4. The fissure carrying fine-grained galena; 5. Streaks of barren, but silicified, country-rock lying within the vein. The maximum and minimum widths of the shear-zone are 100 ft. and 15 ft. respectively.

to 30 per cent. of the gross values; and the freight- and treatment-charges amount to 40 per cent. of the gross selling-price of the concentrates, leaving the mine-owner from 42 to 48 per cent. of the gross value in the ore to cover the cost of mining and milling.

For example, I have said above that the ores mined in the district would average by assay about 10 per cent. in lead and 7 oz. silver per ton. The lead and silver are sold to the smelters,

say at "brokers' quotations," the smelters paying for 90 per cent. of the lead and 95 per cent. of the silver in the ore. At present prices the gross value of the above-mentioned ore would be:

90 per cent. of 200 lbs. = 180 lbs. lead, at 3.5 cts., . . .	$6.30
95 per cent. of 7 oz. = 6.65 oz. silver, at 55 cts., . . .	3.66
Total, ...	$9.96

Of this total gross value, after deducting concentration-losses and freight- and treatment-charges, the mine-owners' residuum of 42 to 48 per cent. amounts to from $4.20 to $4.80 per ton. The cost of mining and milling will be, under varying circumstances, $2.50 to $3.50 per ton, and the net profit remaining will be, therefore, from $0.70 to $2.30 per ton.

Mining.

At least 70 per cent. of all the ore thus far mined in the Cœur d'Alenes has been extracted through tunnels without hoisting or pumping. Of the remaining 30 per cent., which has been hoisted, at least two-fifths has been hoisted through underground shafts, to be subsequently hauled out through tunnels. The Tiger-Poorman is the only mine which has always been operated by shafts from the surface. This large proportion of tunnel-work has been a great advantage to the district.

There are many long and well-constructed tunnels, designed to serve for the final exploitation of the mines. The principal ones are: the Sweeney (Wardner, about 5000 ft. long); the Reed (Wardner, about 5500 ft.); the Kellogg (Wardner, about 12,000 ft.); the Frisco (Gem, about 1200 ft.); the Standard (Mace, about 3000 ft.); the Mammoth No. 6 (Black Bear, about 3600 ft.); the Hecla No. 3 (Burke, about 2400 ft.); the Morning No. 5 (Mullan, about 3000 ft.); and the Morning No. 6 (Mullan, now being driven, 10,000 ft.).

Each of the mines operating the above tunnels has a number of other adits, some of them of great length; but these are of earlier and less elaborate construction, and serve for the working of upper levels.

The principal shafts of the district are the following: The Tiger-Poorman (sunk from surface 1700 ft.); the Hecla (300

ft.); the Standard (in Campbell tunnel, 3000 ft. from the surface, and 850 ft. deep); and the Frisco (in Frisco tunnel, 1200 ft from surface, and 1400 ft. deep).

Measured vertically below the outcrops, the Tiger-Poorman, the Standard and the Frisco mines are nearly of the same depth, 2000 ft. or more.

These three mines are equipped with Corliss hoisting-engines of the same make and size, which were made by Fraser & Chalmers, with 20 by 60 in. steam-cylinders, flat ropes and reels, designed to hoist as much as 2500 ft. They can be run with or without counter-balance, and are very good machines.

No mechanical devices of special interest are peculiar to the district, with the exception of an electric-light hoist-signal system, recently installed at the Standard mine by Doerr, Mitchell & Co., of Spokane. It is possible that this device may in time become more widely known and extensively used. It consists of a signal-box in the hoisting-room and at each station in the shaft. Electric lights are placed in these boxes behind ground glasses, on which are marked the desired signals. Switchboards placed near the boxes enable the station-tenders to turn on the signal lights, which burn until they are turned off by the engineer with a throw-out device. The chairs for landing the cages in the shaft are provided with an attachment which, when the chairs are thrown out to receive the cage, automatically turns on, in plain view of the engineer, a warning light, marked with the number of the level, at which the chairs are out. The signal-lights burn both in the stations from which the signals are given and in the engine-room. This enables the station-tender instantly to see and correct any false signal. It is practically impossible for the engineer to receive a false signal; and, as he knows the exact position of any chairs which may be out in the shaft, there is no excuse for his smashing cages.

Three methods of mining are used in the district: (1) back-stoping and timbering; (2) back-stoping, timbering and filling; and (3) back-stoping and filling without timbering. A description of the methods used at one or two representative mines will perhaps be more instructive than any general account.

At the Bunker Hill and Sullivan, the most interesting fea-

ture of the underground mining is the extraction of wide bodies of low-grade ore by stopes which are filled, as the work progresses, with waste rock sorted from the broken ore. There is usually more than enough of such material to keep the stopes full, and provision has to be made for tramming the surplus waste away. Sometimes this back-stoping is done without any timbering, other than an occasional prop to support a suspicious-looking piece of ground in the roof; but more commonly the stopes are timbered with light square sets. (See Fig. 8.)

In stoping the ore at the Standard (see Fig. 9), it has been found necessary to fill up the stopes with barren material from the vein. This is done by the simple process of sorting out part of the waste rock from the barren streaks and from the walls, and throwing it down among the timbers below. It is quite easy, in most parts of the mine, to secure in this way enough filling to keep the stopes full within two or three floors of the back. As the levels are 200 ft. apart, it is necessary to build massive cribbed chutes up through the timbers.

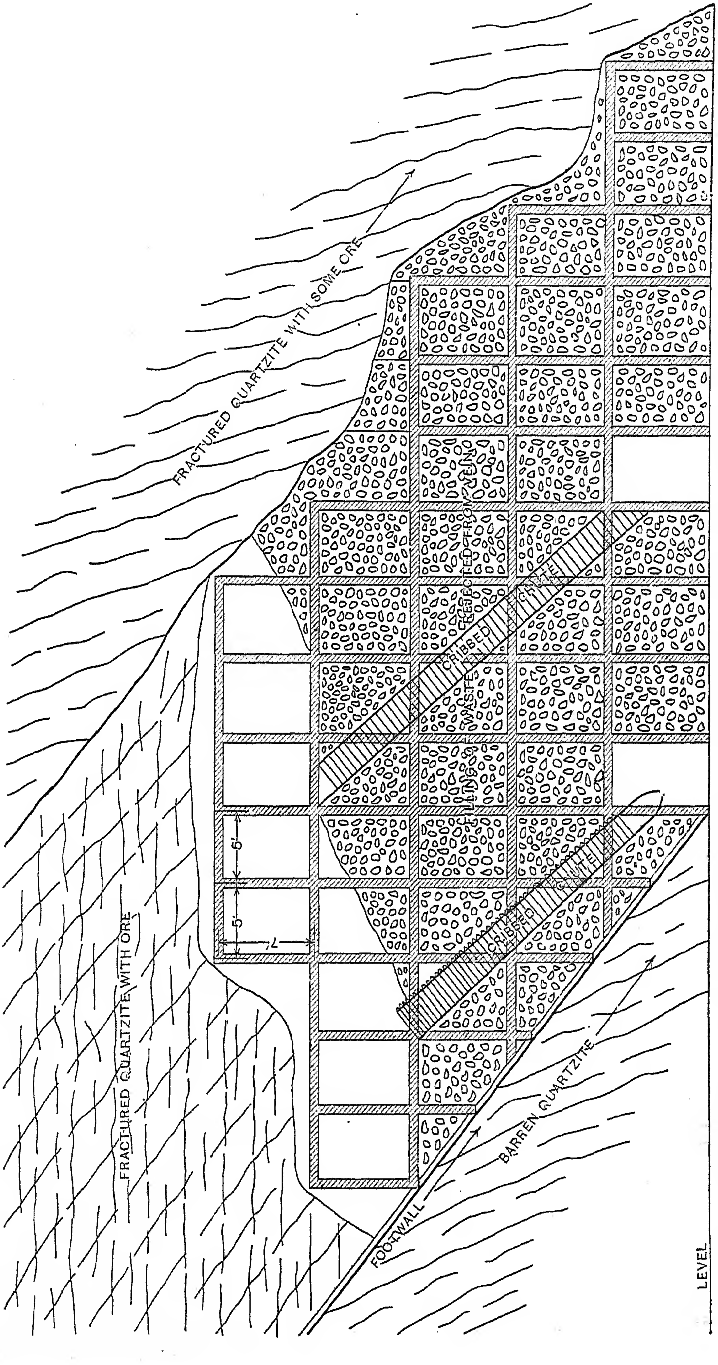
The timbers are of two kinds—square sets and stull-sets. The square sets are 9 by 5 by 6 ft., and are built in the usual way. The stull-sets are merely caps, cut, if possible, long enough to reach from wall to wall, set horizontally and supported by two posts. If the vein is over 15 ft. wide, the cap is made in two sections, joined together on a third post. Three-inch plank is used for flooring or lagging.

The timbering has always been massive and elaborate. Only the abundant supply of cheap timber, which is one of the advantages of the region, renders such heavy timbering economical.

Every facility is provided for the easy handling of the timbers inside and outside of the mine. Each level is equipped with two good hoists, operated by compressed air, to hoist the pieces into the stopes. To provide for these hoists and for the ropes and sheaves, the first floor above the track floor is left open and free from filling.

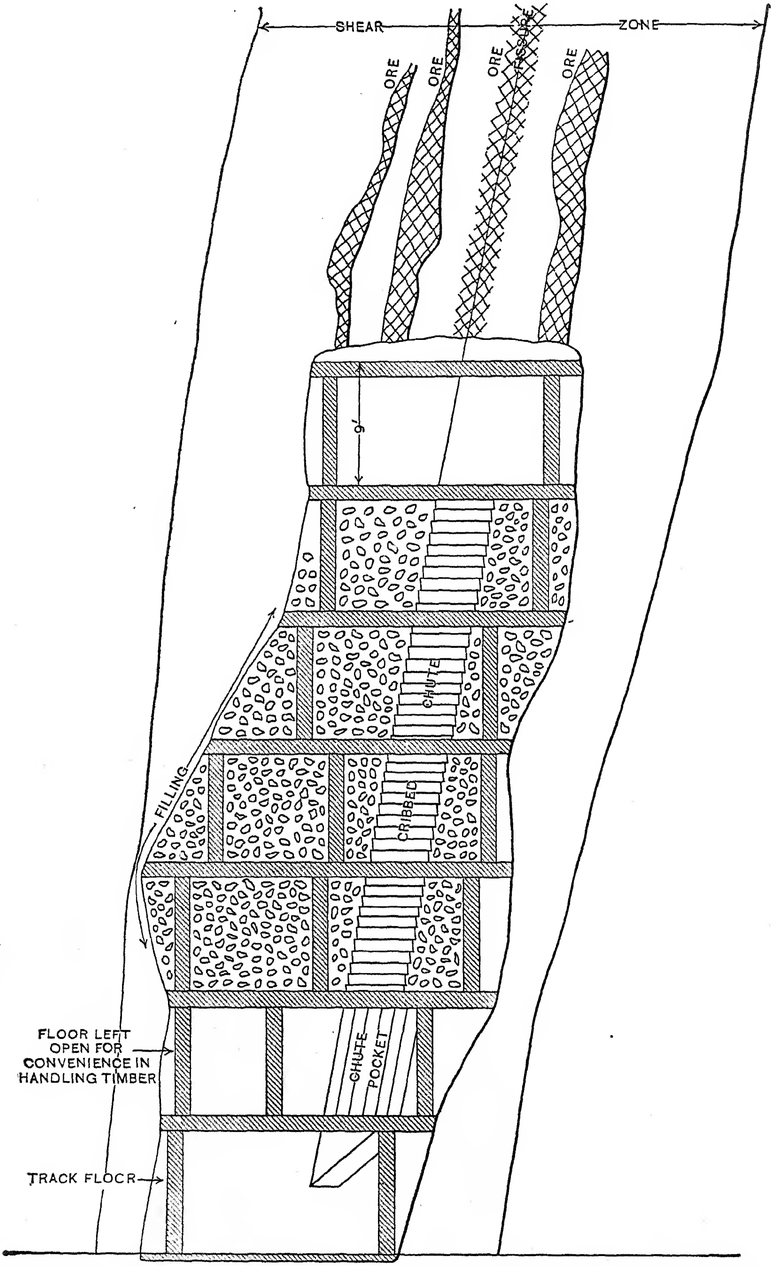
In the Mammoth mine, the ore almost invariably lies in a single streak in immediate contact with the fissure. The shear-zone is much narrower than elsewhere; and the mining is simpler, in that no filling on an extensive scale is required.

FIG. 8.



Sketch, Showing Method of Working Large Ore-Bodies on the Bunker Hill Lode by Means of Light Square Sets and Filling.

FIG. 9.



Sketch, Showing Method of Mining at the Standard Mine, Idaho, by Means of Stull-Sets and Filling.

All the material broken is sent to the mill as concentrating-ore. The timbering consists entirely of stull-sets, with 6 ft. posts (instead of 8 ft., as in the Standard). The chutes are built of planks, instead of the cribbing which is necessary when the stopes are to be filled.

At the Tiger-Poorman, Hecla, Frisco and Morning mines, all the stoping is done with stull-sets, about as in the Mammoth. Very little effort is made to sort the ore before concentrating, or to fill the stopes systematically. It is an open question whether it would not pay better to give more attention to sorting and filling, and less to timbering. With closer sorting the concentrates might be obtained by the milling and transportation of less material; and, as an additional advantage, the stopes would be left in a safer condition.

Use of Water-Power.

All the mines make more or less extensive use of the excellent water-power of the region. An enterprise is now on foot to supply any deficiency of power by means of a 90-mile electric transmission from Spokane Falls. It is expected that, in view of the high cost of coal, this will prove cheaper than steam power. Practically all the power from the neighboring streams is now utilized for running mills, generating electric power, and compressing air.

At three of the principal properties elaborate and interesting water-power plants have been installed; but, by reason of the variation in the water-supply during the year, each plant is, to a greater or smaller extent, supplemented by steam-power.

At the Tiger-Poorman mine, on Canyon creek, electric power, generated by water-power, is used for pumping on a large scale. The pumping-station is more than 1500 ft. below the surface, and the pumps raise the water through that distance in one lift. The plant was built by Nordberg, of Milwaukee, and consists of two independent pumps, which can be run either by steam or electricity, or both. The steam-engines are 18 by 30 by 36 in. cross-compound condensing-engines. The electric motors are each 200 H. P., alternating, 40-cycle, induction-motors, using a current of 2300 amperes, which is brought down the shaft to the machines by a $2\frac{3}{4}$-in. submarine cable.

The pumps are geared, have 4¾ by 36-in. plungers, and fly-wheels, 16 ft. in diameter, which carry 30-in. belts. These pumps have effected a vast economy in the operation of the mine. They raise from 400 to 1200 gallons (averaging about 500 gallons) of water per minute.

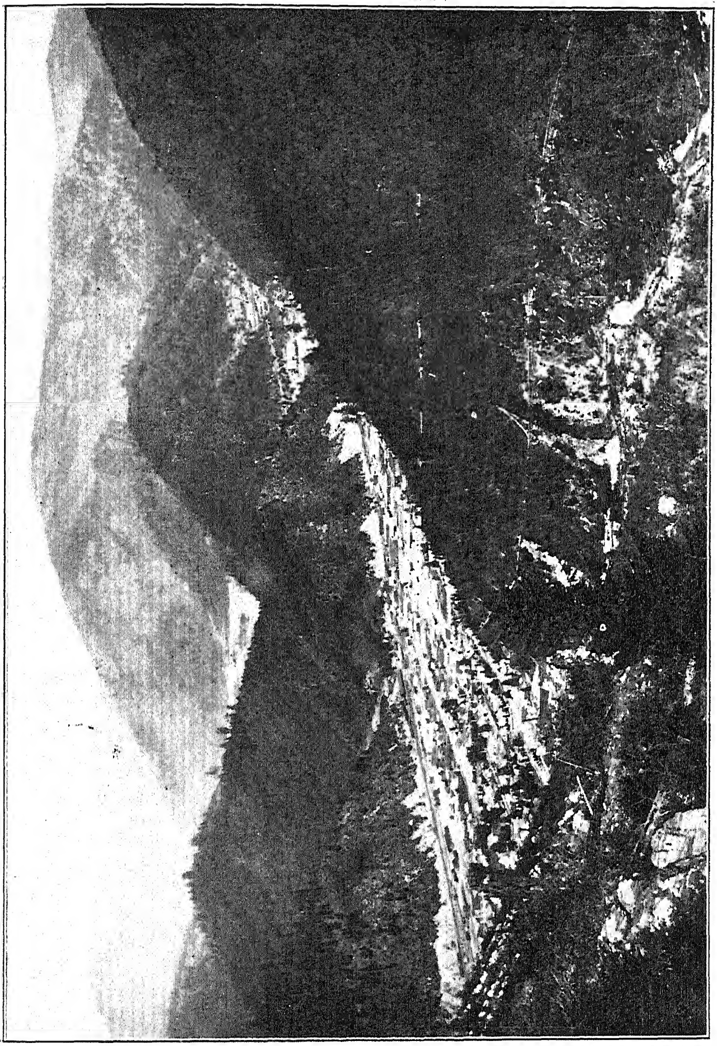
The Morning Mining and Milling Company (see Fig. 15) employs in exploitation a thoroughly well-planned power-system, most of which is used for making compressed air. The water is gathered from various streams high up on the mountains above the compressor-site, and conveyed to the wheels by three pipe-lines of 1400-, 1200- and 130-ft. head, respectively. The 1400-ft. and 1200-ft. heads are delivered by separate nozzles on a Pelton wheel 32½ ft. in diameter. The 130-ft. head is used to drive two 11-ft. Pelton wheels, one on each side of the big one and on the same shaft. There are two compressors, one on each end of the water-wheel shaft. They have compound 18 by 32½ by 42 in. cylinders, with intercoolers. The air is compressed to 28 lbs. in the low-pressure cylinder, and delivered by the high-pressure cylinder at 90 lbs. Running at full speed, these machines compress about 6000 cub. ft. of free air per minute. The pipes which convey this air to the mine cost more than the machinery. They comprise 9200 ft. of 12½-in. pipe, to No. 6 tunnel, at which point the air is divided into two lines of 9-in. pipe, one entering No. 6 tunnel, which will be 2 miles long, and another leading 4½ miles to No. 5 tunnel.

The Bunker Hill and Sullivan Mining and Concentrating Company also uses water-power to help run its large compressor at Kellogg.

Milling.

The process employed is substantially the same at all the mines, and consists of coarse crushing and separation by jigs. Most of the ores contain the galena in segregated streaks of practically clean material, which separates under crushing and is easily caught. The difficulty increases greatly when the galena is intimately mixed with iron carbonate, zinc-blende and quartz. Such ores require much finer crushing, and the use of a much greater number of vanners, buddles, shaking-tables, etc., to separate the slimes. Fig. 18 is an outside view of the Mammoth mill, and Fig. 19 shows the Helena and Frisco mills. The following description of the process at the Stand-

Fig. 10.

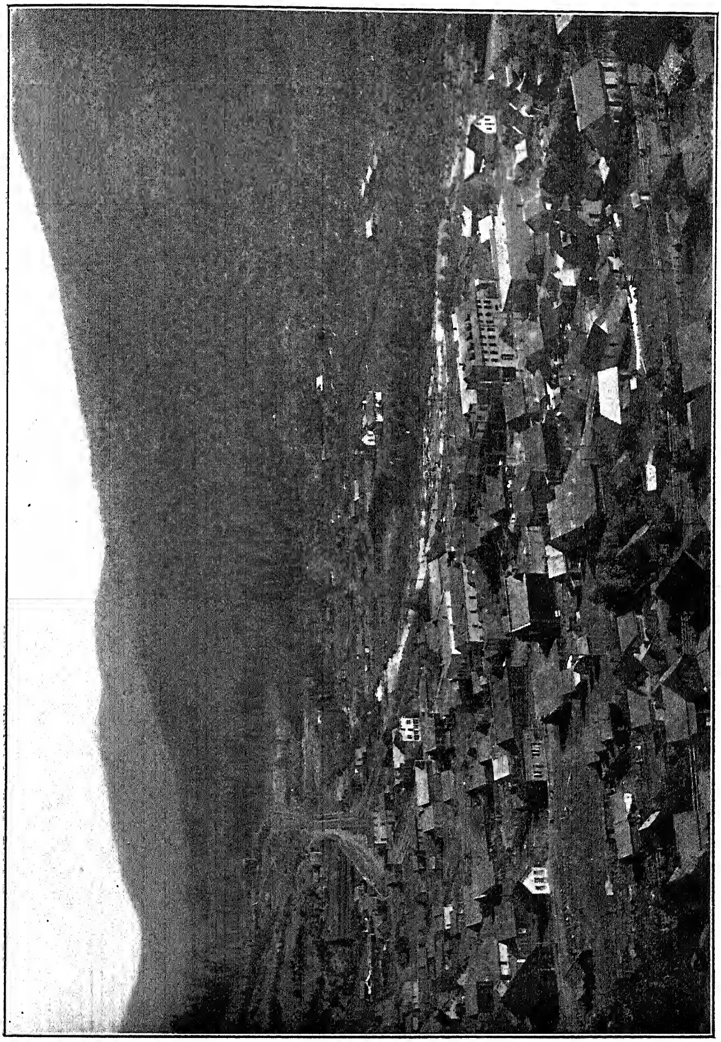


Wallace, Idaho.

FIG. 11.

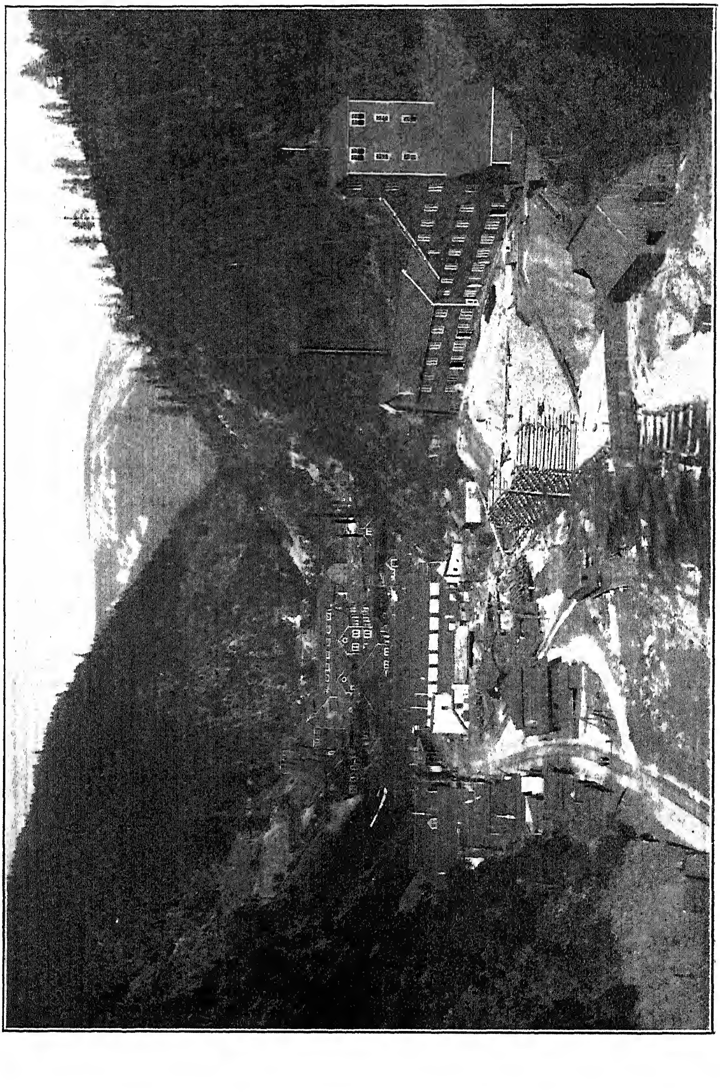
Wardner, Idaho.

Fig. 12.



Mullan, Idaho.

Fig. 13.

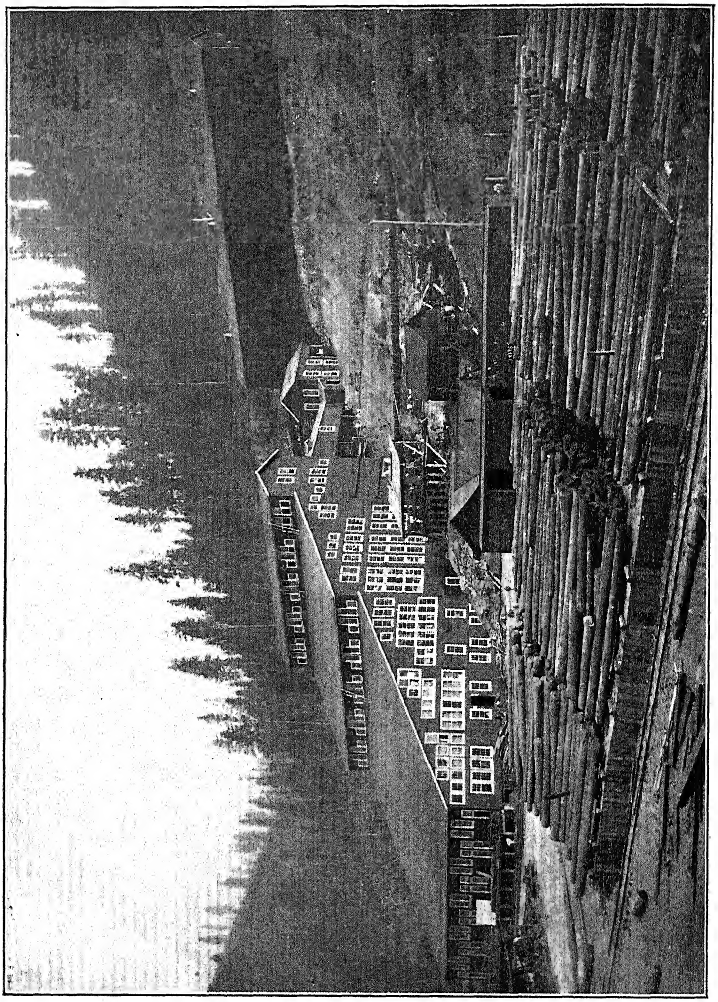


Burke, Idaho. The Hecla Mine is on the right; the Tiger-Poorman on the left.

FIG. 14.

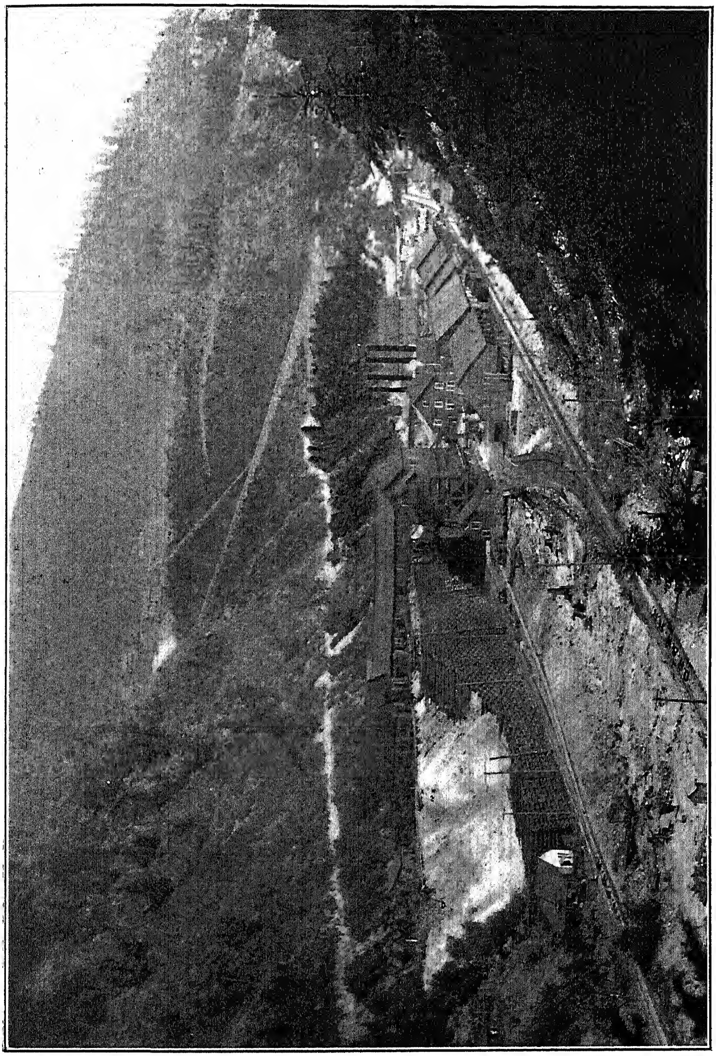
Bunker Hill Mine, Idaho. The white line indicates the outcrop of the foot-wall.

Fig. 15.



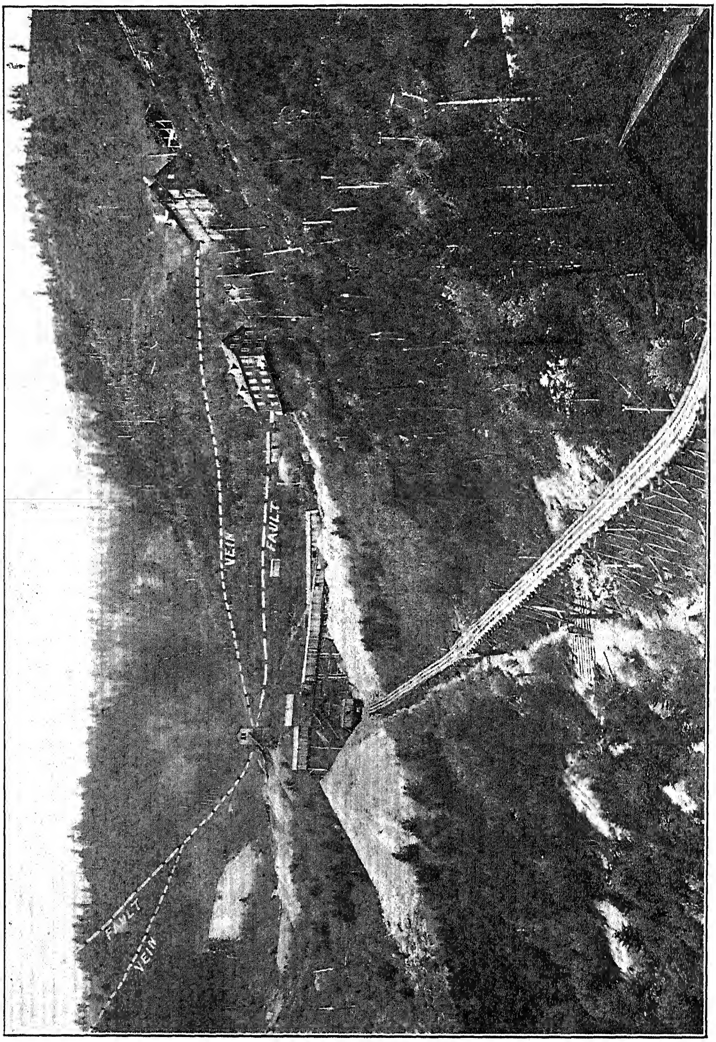
Morning Mill and Timber-Yard, Idaho.

Fig. 16.



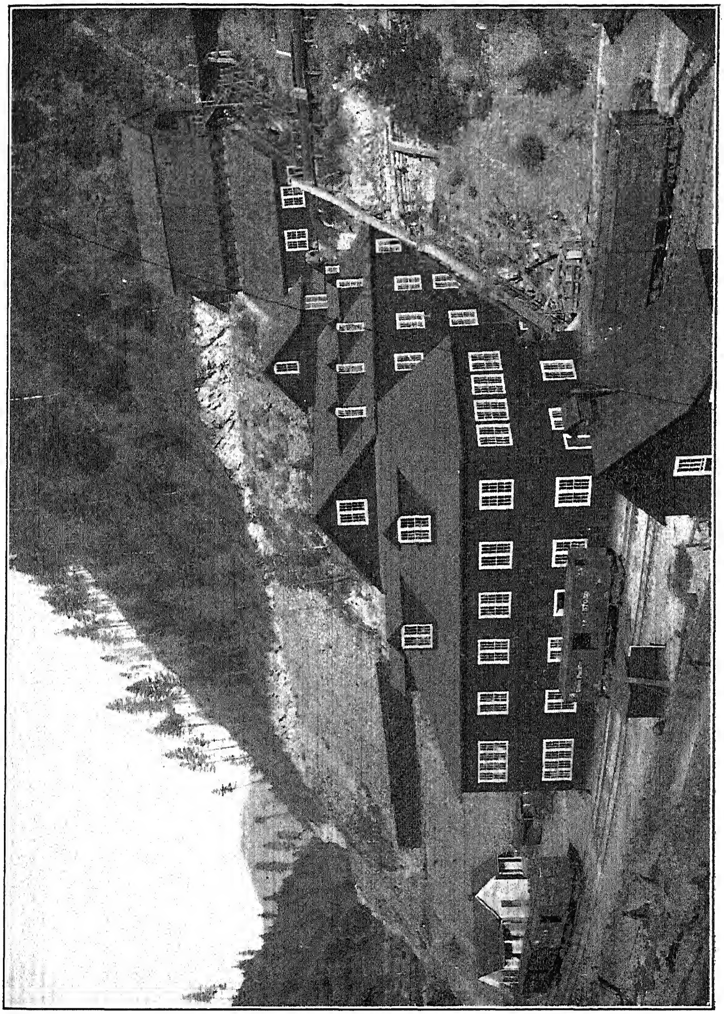
Standard Mine, Idaho. Works at the Mouth of Campbell Tunnel.

Fig. 17.



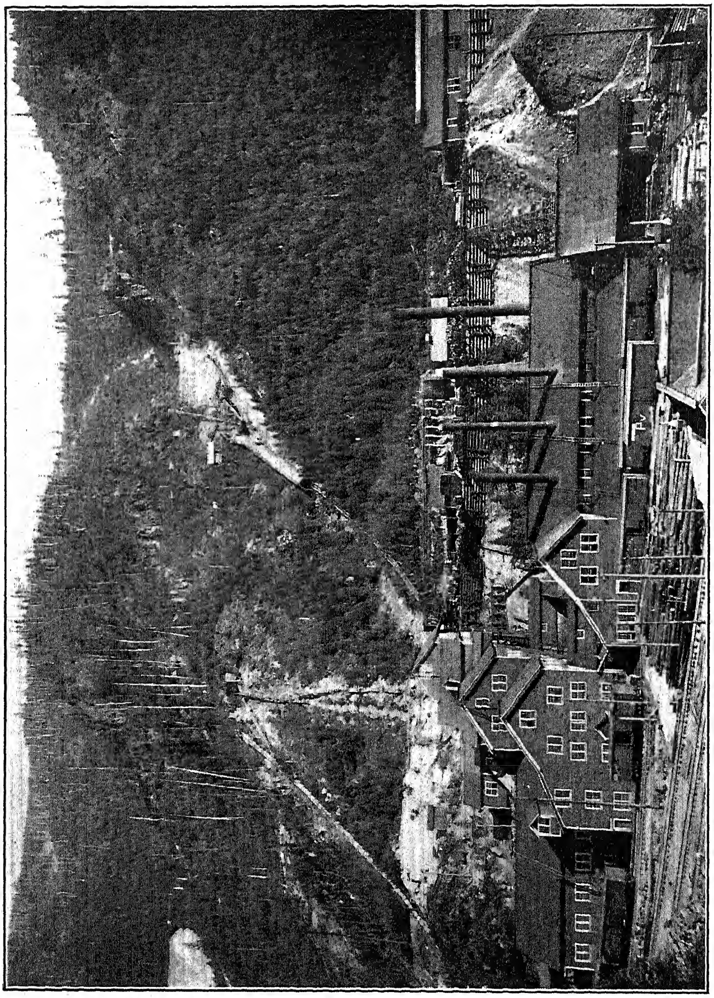
The Mammoth-Standard Mines, Idaho. The white lines show the outcrops of vein and fault.

Fig. 18.



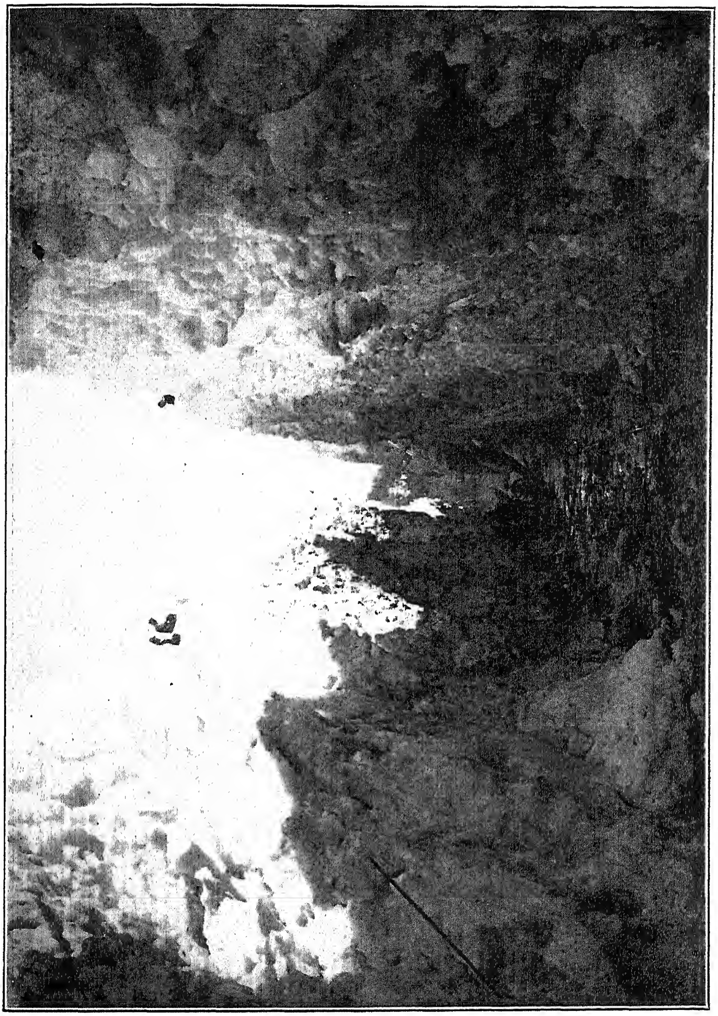
Mammoth Mill, Idaho.

Fig. 19.



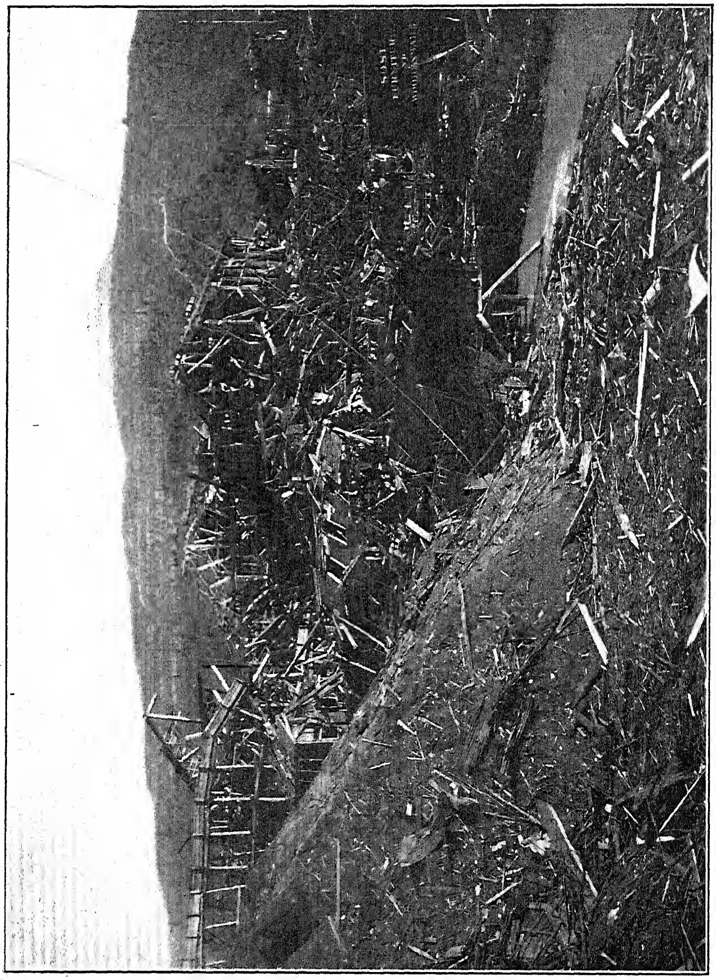
Helena and Frisco Mines and Mills, Idaho.

Fig. 20.



Snow-cut, 85 ft. high, on Canyon Creek, Idaho.

Fig. 21.



Ruins of the Bunker Hill and Sullivan Works, Wrecked by a Dynamite Explosion.

ard mill will serve as a concrete example of the best current practice:

The crude ore from the mine is dumped from railroad-cars into a bin of about 600 tons' capacity, whence it is fed by gravity to a No. 5 Gates crusher, which reduces it to something over 1 in. diam. From the crusher a 15-in. belt-conveyor carries it to another bin, whence it passes by gravity to the roughing-rolls, which reduce it to pieces of $\frac{1}{2}$ to $\frac{3}{8}$ in. diam. From the roughing-rolls it is elevated to a double set of trommel-screens, which size it into an "oversize" of more than 15 mm. diam., and into sizes which pass through 15, 10, 7 and 3 mm. screens. The fines which pass the 3 mm. screens are not jigged, but go at once to V-boxes or hydraulic classifiers. The slimes passing over the V-boxes go to settling-tanks, where the heavier material is caught and sent to Wilfley tables and Frue vanners. All the tailings from Wilfleys and vanners, together with the overflow from the settling-tanks, go to a "canvas" plant of 52 tables of 6 sq. yd. each. Material caught on the canvas-tables is reconcentrated on two Wilfley tables.

Returning to the coarse material classified by the trommels, the oversize, or what passes over the 15 mm. screens, goes to the coarse or "bull" jigs, and what passes through the 15, 10 and 7 mm. screens goes to finer jigs.

Part of the tailings from the coarse jigs is retained as "middlings," to be further treated, and part is allowed to go directly to the creek as worthless. The middlings thus saved are passed through fine rolls and then to Huntington mills, which reduce the pulp until it passes a 40-mesh screen.

The finer jigs, *i.e.*, the 15, 10, 7 and 5 mm. jigs, also select a percentage of "middlings," which are likewise passed through fine rolls, in three sets, according to the coarseness of the material. Thence this material passes to the "middling" jigs, which take out some clean ore. All of the tailings from these "middling" jigs are reground in another set of Huntingtons to 40-mesh. All the material ground by the Huntington mills goes to the Wilfley tables and Frue vanners with the slimes from the settling-tanks and V-boxes above described.

This mill concentrates about 500 tons of crude ore per day. Its machinery consists of the following: a No. 5 Gates crusher; two 15-in. belt-conveyors; six sets of 15- by 26-in. belt-rolls;

four 5-ft. Huntington mills; twenty-eight Hartz jigs, arranged in 14 pairs; 2 lines of trommels; an "oversize" trommel, for middlings; 4 elevators; 18 Wilfley tables; three 4-ft. Frue vanners; and 52 canvas tables.

Power for the main mill is derived from two Pelton wheels, one of 4 ft. diam. under a 32-ft. head, and one of 6 ft. diam. under 235-ft. head. A third (24-in.) Pelton, under 235-ft. head, runs a dynamo for electric lighting, and a fourth runs the Gates crusher.

Transportation.

The transportation of crude ore to the mills is a problem of considerable importance to all the mines except the Tiger-Poorman, the Frisco and the Crown Point, each of which has its mill at the place where the ore reaches the surface. The ore from the Standard, Hecla, Mammoth and Empire State is hauled to the mills by the Northern Pacific and Oregon Railway & Navigation Co. railroads, which reach the mine, and do the work for a reasonable price. The Bunker Hill and Sullivan has a Bleichert tramway (see Fig. 14) about 2½ miles long. The Morning Mining and Milling Company (see Fig. 15) has a railroad of its own, several miles long, built on a 7 per cent. grade, and operated by means of Shea geared locomotives. It has proved very successful, hauling the ores to the mill for less than ten cents a ton, inclusive of delivery of all timber and other supplies to the mine.

The cost of transportation varies from 8 to 20 cents per ton at the various mines.

Fig. 21 shows one of the effects of the labor-troubles in this region, any recurrence of which is earnestly to be deprecated by all parties. This is not the place to discuss the merits of such controversies; but the condemnation of such destructive and lawless violence as is here illustrated should certainly be endorsed by citizens of all political parties and schools of political economy or sociology.

Progress and Prospect of Development.

It is reasonable to expect that the Cœur d'Alene district will be able to maintain its present, and perhaps an increased, output for many years to come. Within the past two years three new properties have been opened up and brought to the divi-

dend-paying stage, while several others have shown more or less ore, and are likely to develop satisfactorily.

The Hercules, which is the latest discovery of great importance, promises to become a mine of the first rank. This vein is at the upper end of Canyon creek, high on the side of Tiger peak. Near the surface the lead-values have apparently been destroyed by leaching; but at the depth of some 400 ft. the ores are found to be very rich both in lead and silver. This is a good instance of that reconcentration of values near the surface which is beginning to be recognized by students of ore-deposits as an important feature in the value of many metal-mines.

Up to date the Hercules has not reached the point of concentrating its ores, but ships them crude, at a very handsome profit.

NOTE.—With regard to the probable extension of the Bunker Hill lode northwestward to the Crown Point, I wish to say that since the body of the text was written a more careful study of the conditions leads me to think that the lode does not pass westward of Deadwood gulch. In saying this, I mean to refer to the lode as a well-defined structural feature. Certain mineralization is found along a course extending between the Viola and the Crown Point; but this is in isolated, disconnected places, and should be considered more properly as belonging to a mineral district than to a distinct vein.

Coking in Bee-Hive Ovens with Reference to Yield.

BY CHARLES CATLETT, STAUNTON, VA.

(New Haven Meeting, October, 1902.)

My attention having been called several years ago to the possibility of increasing the yield of coke per ton of coal, as obtained in certain bee-hive ovens, I called the attention of the Institute to the matter at the New York meeting in 1899. I have had occasion since to witness the indifference with which this matter is ordinarily considered, and, on the other hand, the marked improvement which comes from even a most perfunctory effort in that direction; and I am almost tempted to say that nothing in connection with the coking of coal is at present so important. There are other factors, which are fundamental and necessary; but they have been considered already; while the question of yield is, as a rule, absolutely ignored, or some figure is taken as the result of a special burning of one or two ovens, and the assumption is made that the whole battery is yielding at that rate. The uncertainty of this assumption I may illustrate by saying that, in my own observation, the burning of a single oven in a battery frequently gives, by actual weight, as much as 69 or 70 per cent. of merchantable coke, while the battery as a whole was yielding only an average of 63 per cent.

Only from careful records, checked at least once a month, ot the weight of the coal going to the ovens and the weight ot coke produced, can any correct idea of the actual yield be gained, or methods be modified so as to produce good results; yet, as a rule, the crudest estimates are usually the only available data. In many cases there are reasons for this loose practice. The coal is mined by measurement; the payment for drawing the ovens is in proportion to the amount of coal which goes to them; and, not uncommonly, the royalty is so much a ton of coke, not of coal. The mine-manager is tempted to increase the volume of coal mined which is paid for as a ton, and to do the same thing in charging the ovens. Nor does he

wish the royalty-charge to be changed in any way. The result is that often his records do not truly show within quite a large percentage the actual weight of coal mined and charged in his ovens. Yet until he has accurate information on this point, he cannot tell what is the amount of loss under present methods, or how to improve on them. I venture the assertion that the owners of many plants in the Connellsville region, otherwise well managed, who complacently accept Mr. Fulton's statement that the yield of the Connellsville coal in coke is 66 per cent., would be astonished should they ascertain what is their actual yield.

The effect of a slight increase in the yield per cent. is greater than is usually realized. For instance, if a battery of ovens is yielding 60 per cent., and the yield is increased to 61 per cent., there has been an absolute saving of one-sixtieth, or 1.66 per cent. *of the total value of the coke formerly produced, less the cost of loading*,—since all the other expenses remain the same. I have never yet examined a battery of ovens, where the attention of the management had not been called to the yield, in which it was not possible to make an increase of from 3 to 5 per cent. If, for purposes of illustration, we assume that the former yield was 60 per cent. (which figure does not vary greatly from the general practice), the saving of 3 per cent. would mean a total saving of $\frac{1}{20}$ of the output, and a saving of 5 per cent. would mean a total saving of $\frac{1}{12}$ of the output. Enormous as this difference may seem, it is exceedingly common, and at times is greatly exceeded. I know of a coking-district which, as a whole, is only yielding 55 or 56 per cent., though the coal could readily be made to yield from 65 to 70 per cent.

The loss of the by-products in the 63,000 bee-hive coke-ovens in this country is an appalling waste of natural supplies, and has been a fruitful source of discussion as to the wastefulness of our methods. If, however, I am right in my belief that my own experience fairly represents the conditions at the majority of the ovens in operation, there are at least 1,000,000 to 2,000,000 tons of coke annually consumed and lost in our bee-hive ovens which, by anything like reasonable care and attention, could be saved. As the average value of coke in 1901 was more than $2 per ton, this represents a very large money value.

This waste is worse than useless. The excess of heat available from the gases, as shown by tests of a great variety of coals in the retort-ovens and ordinary tests of single bee-hive ovens, demonstrates to my mind that there is not a good coking-coal which could not be coked in bee-hive ovens by the heat derived from the combustion of its gases alone, and that the burning up of any coke, which has already been formed, is therefore a positive, unnecessary loss.

But more than that: the burning of a portion of the coke necessarily results in the deposition of ash on the remainder. This retards the transmission of heat from the hottest portion of the oven (just above the coke) to the unburnt portion of the coke toward the bottom of the oven; and, moreover, when the oven is watered down, this ash is washed through the pores of the coke and retained there, thus increasing the ash beyond its normal and proper proportion. A careful examination will disclose this ash in the pores of the coke. I have known cases, where the coal was naturally high in ash (and therefore the ash-content was a matter of the greatest importance), in which enough coke was consumed to add 4 per cent. of ash to the entire product. In nearly all cases the increase of ash due to the burning of coke is conspicuous.

The theoretical yield of the coke can be determined within a fair degree of exactness from the proximate analysis of the coal. The coke carries all the ash and fixed carbon, and, even under the best work, a certain portion of volatile matter and moisture. The sulphur will probably be distributed in the coke, as indicated in the analysis. In other words, a coal of the following composition: Moisture, 1.25; volatile matter, 26.30; fixed carbon, 66.05; and ash, 6.40; total, 100—may be expected to give a theoretical yield of $66.05 + 6.40 = 72.45$ per cent. of coke. To this should be added at least 1 per cent. for the moisture and volatile matter, which are retained by average "good coke," so that the theoretical yield of coke made from the above coal can be assumed to be 73.45 per cent. Dividing the fixed carbon, ash and 1 per cent. of moisture and volatile matter by that figure, we would get, for the coke made from this coal: Fixed carbon, 89.92; ash, 8.71; volatile matter and moisture, 1.36; total, 99.99.

In carefully-burned ovens, the ash should not be increased

or the carbon reduced by more than 0.5 per cent. from the figures obtained by calculations like the above, and the volatile matter and moisture may both be reduced below the above figures, though they are often greater. There are various modifying factors, the exact measure of which cannot be accurately determined. Among these is the deposit of carbon from decomposition of the gases. The amount of ash is inversely proportional to the yield, so that increase in the yield at the same time decreases the ash. It is not uncommon to claim an advantage from an increase in a coke, up to a certain point, of ash of suitable composition, as a means of hardening the structure; but I suppose no one will claim any advantage from the ash which does not form part of the structure, but is simply derived from outside sources, either by collection or otherwise. This latter ash is simply paid for as coke, and then must be got rid of. It must not be confounded with that which enters into the structure.

After the coal goes to the ovens, there are several ways in which the ash in the coke produced may be increased above the theoretical amount. A portion may be derived from the dirt-filling around the tunnel-head; a portion from forking the coke from a dirty yard; a small amount from impure water used in quenching; but by far the larger amount comes from the ashes of the coke burnt up in the oven. As the latter is almost in reverse proportion to the yield, it is obvious that the advantage of yield is not confined entirely to the saving of coke, but goes hand in hand with improved quality.

The "commercial" yield will be determined by local conditions and the character of the particular coal. It is the theoretical yield, less the losses in burning and of fine coke in handling, and increased by the ashes and dirt gathered as noted above.

In good coking-coals, high in volatile matter, the "breeze" or fine coke will run 2 or 3 per cent., and the commercial yield should not be more than from 3 to 5 per cent. below the theoretical. It is possible to do better, but anything less good may be considered bad practice. With higher fixed carbon in the coal, and particularly when the coal is low in ash, and will burn or "cut" readily by small leaks admitting air, the difference between the theoretical and the commercial yield may be

between 5 and 10 per cent.; but first-class work should approximate the former figure.

The question of yield is involved to a greater or less extent in all the operations connected with handling the coke-ovens. The conditions which permit of the greatest regularity of drawing and charging, in which the leveling is done as it should be, the ovens are watered down to the best advantage, and are worked to their capacity, etc., are all factors affecting the yield. A plant in which the discipline and management is good will naturally have a better yield than where the management is lax; but after all this is said, there still remains the difference due peculiarly to a special effort, or want of effort, in the way of handling the draft and the oven with special reference to this point.

The principal thing which affects the question of yield is the care and skill with which the drafting, or admission and exclusion of air to the oven, is controlled.

The object and purpose of the drafting is to secure a satisfactory degree of heat at the right time, and as nearly as possible to secure this heat from the gases which are driven off during the process of coking, and which would otherwise be entirely wasted. The more nearly it is possible to completely burn out the coke at a satisfactory temperature, and leave the ovens in first-class condition for the next charge, without burning any of the coke which has been formed, the more nearly do we attain perfect results. The mistake is commonly made of assuming that at all stages of the process, whatever may be the condition of the oven, an increase of draft means an increase of temperature and a decrease of draft a decrease of temperature. The most casual examination will show that this is not the case. At the first stage of the burning, before the gases which will add to the heat by their combustion have commenced to come off, it is possible to cool the oven by excessive draft; and it is common and advisable practice to cover the ovens immediately after drawing, and re-cover them after charging, with a view to their "catching-up" more rapidly. By this means the heat stored in the walls finds its way to the inside of the oven. There is apt to be a time, within the first twelve hours after an oven has "caught-up," when the amount of gas formed is in excess of the ability of anything like an

ordinary draft-orifice to furnish the necessary air to retain the oven at a temperature for perfect combustion. During this time, also, the tunnel-head of ordinary size has great difficulty in disposing of the products of combustion. Later in the process, this condition is reversed, and the amount of air is apt to be in excess of what is necessary to burn the gases which are coming off; and, finally, if the draft is not changed, it becomes greatly in excess of the requirements of the ovens. From this stage to the end of the burning it is thoroughly possible for an oven to continue to cool, even with the admission of a large volume of air. In other words, the heat furnished by the small amount of gas which is coming off, and from the consumption of a portion of the coke, is less than the lowering of temperature caused by the loss of heat from the tunnel-head and from radiation; and this difference is increased by increasing the draft. The attempt to hurry an oven which has been allowed to cool, and which is continuing to cool, while exhibiting a number of "candles," by giving to it an excess of draft, is often indulged in; but it will be found very much better to endeavor to burn the oven so as to keep the heat up to a maximum towards the end of the blast, at the time when it is needed most to reach the coal at the bottom of the oven, rather than to try to replace the heat by an effort to burn a portion of the coke. This effort is always disappointing in results. As a general proposition, I should say that, in nine times out of ten, the drafting is too heavy, and the oven can be brought out in better shape by a more uniform drafting extending over a longer period. As a rule, from 20 to 25 sq. in., in the form of a circular draft at the top of the door (which may be as much as 40 in. high), will be ample for the largest oven which it may be desirous to burn out, while this should be reduced by at least one, or possibly two, changes as the oven is burnt out, so that the amount of air shall at no time be greatly in excess of what is necessary to completely and clearly burn off the escaping gas.

As a rule, I should say that the tendency is to make the tunnel-heads too large. Of course, they have to be large enough to take with sufficient promptness the coal from the larries; but the standard forms of larry will readily discharge into an opening 12 in. in diameter, and I have never yet seen

an oven or a coal which would not give better results with an orifice of that size than with a larger one. Yet larger sizes are common. I know of one manufacturer whose standard size is 16 in., or nearly twice the area of a 12-in. tunnel-head. The latter is abundantly able to carry off, under the best conditions of drafting, the products of combustion; and any excess above this very materially increases the loss of heat, and interferes with the efficiency of the oven.

The small-sized opening may be slightly inadequate at the beginning of the blast; but as the gases come off in smaller quantity and more slowly, it is invaluable in retaining the heat so much needed at the later stage. The smallest tunnel-head I have tried for a 12-ft. oven was 11 in. in diameter; and the results were fairly good. The ordinary difficulties connected with prompt charging limit the size to 12 in. and upward, and I believe that the smallest size that can be readily handled by the charging facilities will be found the best.

The use of lids is extremely desirable. Properly handled, they mean a great deal as regards the matter of yield. The retention of heat in the oven is, of course, of the utmost importance. The ovens should be covered as soon as drawn. They should be covered when charged until they are "caught up;" and as soon as the oven is practically burnt out, the draft should be cut off entirely, and the tunnel-head partially or entirely closed. This will aid in retaining the ovens in the best possible condition, and will prevent the burning up of a large amount of coke. Particularly should the doors and jambs be kept tight, and the smallest cracks stopped. The consumption of coke from this cause is enormously larger than would be supposed at first sight.

It is almost impossible to make any improvement in the matter of yield without keeping records in such shape as to show what are the good or bad results of any method of treatment. It is absolutely necessary, therefore, that arrangements be made to calculate, from either the railroad- or the larry-weights, to within at least 0.25 per cent. of the actual yield, within one or two days from the end of each month. With this, there is the strongest incentive to endeavor to improve; and without it, there is the strongest reason for making no change, since it cannot be known whether a change is advantageous or

Coke-Ovens—Monthly Efficiency-Record—Coke-Ovens.

1902.	Tons Coke Made.	Tons Coal Used.	Yield in Per Cent. Coal Used.				Number of Ovens Drawn.			Coal Charged Per Oven.			Monthly Efficiency Record.	1902.
			Theoretical.	Practical.	Actual.	Efficiency Percent.	Possible.	Actual.	Efficiency Per ct.	Possible Tons.	Actual Tons.	Efficiency Per cent.		Remarks.
			Percent.	Per cent.	Per cent.	Percent.			Per ct.			Per cent.	Percent.	
Jan...	8911.65	13957.00	76.95	67	63.85	95.30	3405	2925	85.93	5.25	4.77	90.85	74.39	
Feb...	8565.10	13215.70	77.59	67	64.81	96.73	2995	2985	99.66	5.25	4.42	84.19	81.15	More 48-hour coke was made than 72-hour coke.
Mar...	9107.05	14251.80	77.38	67	63.90	95.37	3575	2888	80.78	5.25	4.93	93.90	72.33	
Apr...	8853.20	14403.55	77.30	67	61.46	91.73	3416	2910	85.18	5.25	4.95	94.28	73.67	The loss was in burning the coke overtime.
May...	9341.65	14821.6	74.7	67	63.02	94.06	3455	3032	87.75	5.25	4.88	92.95	76.72	The loss was in small charges.
June..	6977.85	10803.8	77.1	67	64.58	96.38	3057	2689	87.96	5.25	4.18	79.61	67.49	The charges for the ovens are too small.
July...	5506.45	8448.4	75.0	67	65.20	97.31	1812	1644	90.72	5.25	5.33	101.52	89.62	All departments in the coke manufacturing increased in efficiency, hence the good result.

not. It is impossible to give a form for such a record, because it will vary with each plant; but I would call attention to the fact that that portion of the coke and coal on the yard or in bins, or in transit at the beginning and end of each month, if carefully estimated, cannot introduce a large error; and any such error which is made one month is balanced in the succeeding months; so that, if actual weights be taken of the coal that goes to the ovens and the coke that is shipped away in each month, the other amounts being estimated, the results will be very close.

I submit the form on page 279 as a valuable one for keeping the monthly record and comparing the work month by month. It is a copy of a report from a plant in actual operation.

The monthly efficiency-record will be found by multiplying the efficiency per cent. of yield; the efficiency per cent. of coal; and the efficiency per cent. of the number of ovens drawn, and will no doubt astonish some coke-makers when they apply this form to their own operations. The theoretical yield is determined as explained above; and the practical yield is something smaller, depending on the tendency to make fine materials or "breeze," the composition of the coal, the condition of the ovens and equipment, etc.

As promptness and regularity in all the steps of the coke-manufacture are essential for high yield, the following form of daily report will be found of service in locating promptly weak points in the work. It should be transferred to a scratcher in the office in such form that the percentage for each day follows that of the previous day in a vertical column, and changes can be noticed at a glance.

Coke Department—Daily Efficiency-Record.

	Required.	Actual.	Efficiency-Record. Per cent.
Drafting:			
Ovens burnt out on time,	A	B	See note below.
Ovens ready to draw,	C	D	
Ovens standing over,	E	F	
Drawing:			
Number of ovens,	G	H	
Promptness (hours),	I	J	
Coal Supply:			
Number of larries,	K	L	
Charging:			
Number of larries,	M	N	
Promptness (hours),	O	P	

Loading Coke:	Required.	Actual.
Cars furnished,	Q	R
Cars loaded,	S	T
Loaders,	U	V

A. The number of ovens charged to come out to-day.

B. The number of ovens charged to come out to-day, which came out in the proper time.

C. The ovens charged to come out to-day and those brought over from previous days.

D. All ovens ready to pull at the proper time.

E. Is always zero.

F. The ovens ready to pull at the proper time which were not pulled.

G. All ovens ready to pull at the proper hour. The number is the same as D.

H. Number of ovens pulled.

I. Number of hours from the time the first oven is started until the last is finished.

K. The number of larries of coal needed to supply the ovens that should have been drawn that day. L, the number available.

M. The number of larries of coal needed to charge the ovens drawn that day.

O. The number is the same as I. The larries used in charging start later, but should not take a greater number of hours than are required for drawing.

Q. The number of cars asked for from the railroad company. It is seldom less, and is often more than the number required for one day's output of coke.

R. The number of cars furnished.

S. The number of cars to be loaded—evidently the same number as R.

U. Is the number of loaders required to load R.

V. The actual number of loaders.

NOTE.—The "efficiency-record per cent." may be illustrated as follows: Suppose A is 100 and B 75; then the efficiency-record of "ovens burnt out on time" is 75. If 25 ovens were left over from the previous day, the full number which should have been ready to draw to-day (C) would be 100 + 25 = 125; but as 25 ovens were not burnt out, D is only 100, and the record per cent. of "ovens ready to draw" is 80. "Ovens standing over" may be due to defective drafting, failure to draw, or other causes. As E is always zero, it is not practicable to represent the ratio between E and F by percentage. Under "drawing," G to-day is 100, and if only 65 (H) are drawn, the percentage efficiency on this line would be 65. If I should be 8 hours and J is 10 hours, the efficiency-record per cent. for "promptness" would be only 80. The coal-supply should always be enough for the regular number of ovens due each morning, or 100 (K), but if there is only coal enough for 90 (L), the efficiency-record per cent. of coal-supply would be only 90. The total amount of coal actually needed on any day might be more or less than the normal. To-day M would be only 65, and if N is 65, the charging efficiency-record per cent. is 100. O should in this case be 8, and if P were 12, the "efficiency-record per cent." of promptness in charging would be only 66.66. If Q is 10, and R is 5, the car-supply for the day is only 50 per cent. of what it should be, and if S is 5 and T is 3, then the loading of cars furnished is only 60 per cent. of what it should be. U and V simply enable the superintendent to know whether the failure in loading is due to want of men or from some other cause. The efficiency for the day is in the following order: Car-supply, 50; loading cars, 60; drawing, 65; promptness in charging, 66.66; ovens burnt out on time, 75; promptness in drawing, 80; normal coal-supply, 90; charging, 100. The weakest points in the actual operation of the ovens are "Drawing" and "Ovens burnt out;" and the normal coal-supply and promptness should also be looked after. As the coke-boss is usually not strong at figures, the report should be turned in, and the percentage calculated at the office.

Notes on Brazilian Gold-Ores.

BY ORVILLE A. DERBY, SÃO PAULO, BRAZIL.

With Introduction by Prof. J. F. Kemp, New York City.

(New York and Philadelphia Meeting, February and May, 1902.)

INTRODUCTION.

THESE notes, received by me from the author, who is not at present a member of the Institute, are presented as having a special interest for students of the genesis of ore deposits. The statements of Mr. Derby under the head of "Gold in Granitic Apophyses" show that, in Brazil, certain pegmatites are metalliferous. In the United States, pronounced dikes or veins of this type have not been found productive.*—J. F. K.

In view of the recent important discussions before this Institute on the genesis of metalliferous deposits, certain features in the occurrence of gold which seem to be more clearly developed in Brazil than elsewhere can hardly fail to be of interest. As the observations here recorded have necessarily been of a somewhat cursory character, they will be presented in the form of brief notes, without any attempt to draw conclusions as to their genetic significance.

Gold in Gneiss.—The statement made by me many years ago† that in the districts of Campanha and São Gonçalo, in southern Minas Geraes, gold occurs in gneiss, can now be reaffirmed in the most positive manner, on the strength of a recent examination of fresh material, confirmed by the testimony of an experienced mining captain from the Morro Velho mine, who, being skeptical on this point, made a prospecting-tour in the district. The specimens examined, though so far decomposed as to be readily disaggregated, were clearly of

* See Lindgren on "The Character and Genesis of Certain Contact-Deposits," *Trans.*, xxxi., 242.

† *Am. Jour. Sci.*, 1884; vol. cxxviii., p. 443.

typical gneiss, with the characteristics of a sheared granite, composed principally of feldspar and quartz, nearly free from mica, and showing no evidence of having contained more pyrites than the infinitesimal proportion usual in such rocks. Test-pieces, broken with the greatest care from the center of large blocks, so as to give perfectly fresh fractured surfaces, and to be free from open joints and quartz veins (even microscopic ones), were crushed and washed in porcelain vessels to avoid all possibility of any foreign admixture. Under these circumstances, samples of the size of a butternut were generally found sufficient to give distinct colors of gold in very fine, but often beautifully crystallized granules.

The heavy residue was composed principally of zircon, in beautifully sharp and splendent crystals, showing no signs of wear—a character which confirmed the supposed granitic origin of the rock. The iron oxides, magnetite and ilmenite, which usually occur in such rocks, were unusually scanty in amount; and no pyrite, either fresh or altered to limonite, could be detected under the microscope. The amount of gold in the specimens examined was calculated at from 5 to 10 grammes per metric ton; but from the extent of the old workings it is evident that much richer rock occurs in the district, which at one time rivaled in production the more celebrated auriferous districts of the same State, which are characterized by sulphide ores. This mode of occurrence, independent of sulphides, and more or less independent of quartz-veins as well, seems to predominate throughout the district.

Gold in Granitic Apophyses.—Aside from the well-known example of the Passagem Lode, so minutely studied by Dr. Hussak, a number of others of somewhat different character occurring in the same range have been briefly discussed elsewhere by the writer.* These, having the appearance of ordinary quartz-veins, are characterized by included patches of kaolinized feldspar, or of mica, carrying one or more of the characteristic granitic accessories, zircon, monazite and xenotime, and are evidently extreme phases of granitic (pegmatitic) dikes and stringers. Throughout the Diamantina district it is rare to see an outcrop of these veins which does not show signs of having

* *Am. Jour. Sci.*, 1899, vol. clvii., p. 343.

been worked, or at least prospected, for gold. The only one examined that is certainly gold-bearing was close to the great diamond-working of São João da Chapada, in which a fine example of the quartz-kaolin type is presented. This cuts a somewhat sheared diabase, and consists of vein-quartz of the ordinary aspect, with partings and patches of green muscovite, which give an abundant residue of rutile and monazite. A lode which has been quite extensively worked at Bandeirinha, about 20 miles to the southward, is believed to be of this character, since the concentrated sand gives an abundance of beautifully fresh monazite of the peculiar prismatic type described in the above-mentioned paper. Unfortunately, this mine could not be examined.

Gold in Lodes of Sulphides and Carbonates.—The great mine of Morro Velho, in the Sabará district of Minas Geraes,* is of this character, as are also the adjacent mine of Raposos and that of Cuyabá (at least as regards its main lode), about 10 miles distant. All these belong to the St. John del Rey Mining Co. The sulphides are pyrite, pyrrhotite, arsenopyrite and chalcopyrite—zinc-blende and galena occurring only as great rarities. The gangue is a finely granular mixture of carbonates of iron, magnesia and lime (siderite, dolomite and calcite, apparently in this order of abundance), with quartz and apparently also a feldspar, albite, which in the mass of the ore is distinguishable with difficulty from the quartz, but appears in great perfection and beauty in the vugs. Typical vein-quartz occurs only in subordinate amounts and local developments.

The country-rock at all three mines is a highly-sheared calc-schist, which, on account of the development of micaceous or chloritic elements, has generally been taken for a micaceous schist, and in which it is interesting to note that the predominant carbonate is that of lime—those of magnesia and iron being very subordinate in amount, if not entirely absent. The gold-tenor runs about 12 to 20 grammes per ton at Raposos and Cuyabá, and about twice as much at Morro Velho. The lodes are characterized by great size, particularly in width, that of Morro Velho, which has been more fully opened up, having been worked for about 600 ft. in length with a very

* An excellent account of this mine will be found in the *Eng. and Min. Jour.*, vol. lxxii., p. 485, Oct. 19, 1901.

uniform cross-section, having a mean width of about 45 ft., to the depth of more than a mile on the dip, or 3100 ft. vertically below the shaft-mouth.

According to notes kindly furnished, from a considerable series of analyses, by Mr. Wilder, the chief metallurgist at Morro Velho, the ore contains 30 to 40 per cent. of sulphides, 30 to 40 of carbonates, and 20 to 30 of quartz. Pyrrhotite is the predominant sulphide; siderite the predominant carbonate. In an assay-sample, representing the ore put into the bins during a period of several months, the pyrrhotite was determined by Mr. Wilder at 28.5 per cent. The other sulphides were calculated as follows: arsenopyrite, 5.04; pyrite, 2.50; chalcopyrite, 0.66 per cent., giving 36.70 per cent. for the total sulphides. In this sample the residue insoluble in acids (mainly quartz) amounted to 24.10, leaving 39.20 per cent. for the carbonates. In the lean portions of the ore the carbonates increase in proportion at the expense of both the sulphides and the quartz; and the miners consider that a fair amount of silica, shown by small, scattered eyes of smoky quartz, is a favorable indication of good ore. When, however, the quartz becomes excessive, and the lode-stuff takes on the appearance of ordinary vein-quartz, the contents in sulphides and gold run low. Also, when the pyrite runs high, the gold-value seems to sink.

To test the prevailing impression that an abundance ot arsenopyrite is a favorable indication for gold-value, Mr. Wilder constructed the gold- and arsenic-curves of a large number of assays, with the result that he found divergences quite as frequent as coincidences.

A certain proper mixture of the various sulphides and of the carbonates and quartz of the gangue seems to give the best values. A thin line, characterized by lead sulphide, gave most extraordinary values; but it soon ran out, and no other like it has been known within the experience of the present staff.

At Morro Velho the ore, except as to variations in the relative amounts of the various constituents, presents no well-marked differences in structure and composition throughout the immense mass. At the other two mines, a considerable part of the lodes is constituted by an exceedingly hard, jaspery

mixture of carbonate and quartz, banded black-and-white, and comparatively free from sulphides, which envelopes the mass of structureless, workable ore, and is known as *caco* (potsherds), by reason of its somewhat slaty character. Except for its banded structure, and the presence of a certain amount of graphitic matter, this material shows nothing in microscopic sections to distinguish it from the leaner portions of the Morro Velho ore. Graphite occurs in the Morro Velho lode also, but is there confined to a slicken-sided zone on the contact of the eastern end of the lode with the country-rock. This zone, known as "the slide," has been a constant feature from the surface down to the bottom of the present workings, and recalls a somewhat similar zone, also graphitic, described by Hussak,* in the Passagem mine.

A singular feature, now appearing in one part of the Cuyabá lode, is a considerable mass of a coarse-grained greenish rock of granite texture, composed essentially of plagioclase feldspar, thickly sprinkled with arsenopyrite, and showing irregular fracture-zones, filled with green chlorite. This mass, which carries a little zincblende, occurs in the width of the better ore, with which it appears to have a genetic connection. This also recalls a feature of the Passagem lode.†

Feldspar, in the form of beautiful crystals of albite, is common in the vug-linings at Morro Velho, and is evidently a constituent of the gangue as well, though, owing to the fineness of the grain and the absence of observable twinning, it is distinguishable with difficulty from the quartz. A test-sample freed, as far as practicable, from soluble and heavy constituents by means of acids and a heavy solution of such specific gravity as barely to float quartz, gave alumina and soda corresponding to nearly half of the residue thus purified.

Small proportions of titanium, iron, magnesia, potash and lime, in this analysis, indicate the presence in the ore of other minerals, which, for lack of time, have not been identified. A large water-filled vug was recently struck in the lowest level

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* *Zeit. f. Prakt. Geol.*, Oct., 1898, p. 345.

† By chance, a specimen is at hand from the Sugar Loaf lode at Coolgardie, W. Australia, which resembles this rock in appearance, but is so fine-grained that the character of the feldspar cannot be made out without an analysis. This rock is highly micaceous, and aplitic rather than granitic in texture.

of the Morro Velho mine, under circumstances which indicate that it was most probably a sealed flask, containing original lode-water. The walls of the vug presented, instead of the usual lining of beautiful crystallizations of carbonates, quartz, sulphides and albite, a thin earthy coating of gelatinous silica with calcite, and an easily soluble foliated iron silicate (nontronite?). On dissolving these elements, extremely minute cubes of pyrite and irregular magnetic grains of pyrrhotite were obtained. The water, of which a complete analysis will be presented elsewhere, contains, in the form of silica, carbonates and sulphates, a residue of the elements from which this coating was derived, and—with the possible exception of arsenic and gold—all the elements of the lode itself.

This type of ore-body, exemplified by the Morro Velho lode, presents the following characteristics, which must be considered in any discussion regarding its mode of origin:

1. Notable width, combined with a lenticular or stock-like form of the cross-section.

2. Notable constancy in form, mineral composition and bullion-value, throughout a great length of lode.

3. The predominance of carbonates in the gangue and of pyrrhotite among the sulphides.[1]

4. The presence of a feldspar in the gangue.

5. The presence of free carbon, either disseminated throughout the ore or segregated in zones of movement.

6. The aplitic texture of the ore.

7. The presence of confined mine-water, containing in solution all, or nearly all, the chemical elements of the ore-body, and forming by secondary deposition all, or nearly all, of its characteristic minerals.

8. The absence in the ore-body, and in the country-rock immediately adjoining it, of well-characterized eruptive rocks, unless the peculiar type of feldspar rock of the Cuyabá lode can be taken as such.

A Consideration of Igneous Rocks and their Segregation or Differentiation as Related to the Occurrence of Ores.*

BY J. E. SPURR, CONSTANTINOPLE, TURKEY.†

(New York and Philadelphia Meeting, February and May, 1902.)

CONTENTS.

* Published by permission of the Director of the U. S. Geological Survey.

† Since returned to the United States, and now again in the service of the U. S. Geological Survey.—R. W. R.

Introduction.

In a new field like that of the study of ore-deposits, it is hard to keep all sides of the question in sight at once; to realize that the laws worked out for certain types of ore-deposits in one region do not apply to deposits of apparently similar ores the world over. Thus have arisen our most hotly-contested controversies, over such questions, for instance, as: Whether bedded ores are mechanical sediments formed at the same time with the enclosing rock, or were introduced later by solution; Whether metals have been deposited by ascending or by descending waters; Whether they are derived from the immediate wall-rock, from the rocks of the whole district in which they occur, or from the "barysphere"; Whether they are deposited in pre-existing cavities or are replacements; and so on.

The researches of the past score of years or so have rather dampened the heat of these discussions. Investigators have been led to recognize in nature a complexity which permits most of the advocated theories to find their place as factors mutually co-operating to constitute the intricate system which determines the occurrence of ores as we now find them. I think most of us agree with Prof. Van Hise,* that "for many ore-deposits a complete theory must be a descending, lateral-secreting, ascending, descending, lateral-secreting theory." Indeed, all this—and more!

Van Hise's discussion of the work of underground water in forming ore-deposits seems to me the best general contribution of recent years, not excepting the famous treatise of Posepny. A masterly discussion like this fills, for the moment, the whole mind of the reader, and he might thus fail to consider the importance of principles which the author has purposely omitted. Kemp, Lindgren and Vogt, in their discussions of Van Hise's paper, have called attention to certain of these principles, especially those involving the connection of igneous rocks with ore-deposition, or *ore-segregation*, as I would like to call it.

It is concerning this part of the field that I wish to present some considerations, limited in extent and detail by my lack of

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* "Some Principles Controlling the Deposition of Ores," *Trans.*, xxx., p. 173. *Genesis of Ore-Deposits*, p. 428.

access to a wide range of literature, and by the difficulty of the subject itself. With most of Van Hise's conclusions, I may remark, I fully agree.

For the ideas herein set forth I can claim, of course, only a certain amount of originality. It will be seen that my views (which I have previously announced, although not in such compact form as this*) resemble, more or less, those of Lindgren† and Kemp‡ in this country, and De Launay, Beck and Vogt§ in Europe, but especially the last named.

I. The Relation of Ore-Deposits to Igneous Rocks in General.

Two important points have come to be agreed upon by most of the best writers on ore-deposits, namely: (1) That ores in general were *originally* derived from igneous rocks; and (2) that *present* ore-deposits are closely associated with actually-exposed eruptives.

Probably at least nineteen out of twenty important ore-deposits (excepting those of iron) are acknowledged to have a genetic connection with associated rocks of igneous origin. Especially well-marked is the connection of *ore-regions* or *zones* with areas or belts of igneous activity.|| The interdependence of eruptive rocks, hot springs and many ore-deposits has at last attained the dignity of a general law.

The hot springs often owe their heat, and hence their upward propulsion, to igneous masses, while the ore-deposits are the direct work of both the other two, the material being largely derived from the rocks and the concentration being effected by the waters. Moreover, the lines of weakness (of

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* J. E. Spurr, "Economic Geology, Mercur Mining District, Utah," *16th Annual Rpt. U. S. Geol. Surv.*, Part II., pp. 395, 449 (1895); "Geology of the Yukon Gold-District," *18th Annual Rpt. U. S. Geol. Surv.*, Part III., p. 297 (1898); "Quartz-Muscovite Rock, from Belmont, Nevada," *Am. Jour. of Sci.*, 4th series, vol. x., Nov., 1900, p. 355.

† Waldemar Lindgren, "Character and Genesis of Certain Contact-Deposits," *Trans.*, xxxi., p. 226, and *Genesis of Ore-Deposits*, p. 716.

‡ J. F. Kemp, "The Rôle of the Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., p. 169, and *Genesis of Ore-Deposits*, p. 681.

§ J. H. L. Vogt, "Problems in the Geology of Ore-Deposits," *Trans.*, xxxi., p. 125, and *Genesis of Ore-Deposits*, p. 636.

|| J. F. Kemp, "The Rôle of the Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., 196, 197, and *The Genesis of Ore-Deposits*, pp. 707–709.

faulting, etc.) determined by, or at least coextensive with, the intrusion of the molten masses, frequently form the channels of the springs, and thus operate to restrict the ore-deposits to the eruptive zones.

The broad explanation of this association is plainly contained in the proof which we now possess, that the eruptive rocks contain in varying amounts the rarer elements (among them, most of the metals), in addition to the common ones.

In the stratified rocks, on the other hand, the metals, though present, seem to be in general less abundant.*

II. The Distribution of Metals in Sedimentary Rocks.

All sediments were probably derived in the beginning from the destruction of igneous rocks, but the elements thus derived attain through mechanical and chemical surface agencies a degree of concentration hardly equalled in the igneous rocks themselves. Thus calcium becomes concentrated into limestones, and silicon into great volumes of sandstone or quartzite. Among the commercially valuable minerals, salt, gypsum, phosphate of lime, borax and others have thus become concentrated. These facts indicate that metals also must be similarly dissolved out and dispersed. In the case of some of the metals, we know that they are re-deposited in concentrated form. By chemical and mechanical action, iron is concentrated in bogs, in greensands, and in ferruginous shales and sandstones, there to yield, after some further concentration, such notable deposits as the iron-ores of the Lake Superior region. By chemical action, manganese is concentrated, not only in bogs, but on a large scale in marine sediments, such as shales and limestones, so that most of the commercially important deposits are derived, through the medium of further concentration, from these sources. By mechanical and chemical action such rarer metals and minerals as gold, platinum, diamond, tin-ore, monazite, garnet, etc., are very highly concentrated in river channels and in marine shore-deposits. Examples of the enormous efficiency of surface concentration in producing valuable deposits of the rare metals are furnished

* J. F. Kemp, "The Rôle of the Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., p. 175, and *The Genesis of Ore-Deposits*, p. 686.

by the world's gold-placers, the Cape Nome beach-sands, and (according to some authorities) the South African auriferous beds. As regards platinum, nearly *all* the known concentrations, so complete as to be commercially valuable, have been effected by surface-agencies.

But, on the one hand, iron and manganese are common elements; and, on the other hand, gold, platinum, tin-stone, etc., are relatively insoluble; and thus their concentration may be explained. Concerning the metals (such as silver, copper, lead, zinc, arsenic, antimony, etc.), which are at the same time relatively rare and relatively soluble, no such satisfactory conclusion has been reached. That, upon disintegration of the igneous rocks, these metals largely go into solution in surface-waters, there is no doubt. These waters (apart from those which pass underground, where we know that the metals are frequently precipitated in concentrated form*) find their way into lakes, and especially into the oceans. What becomes of the metals which they hold in solution?

Are they precipitated either in concentrated or in evenly disseminated form, or do they remain in solution? If it be true, as I think it is, that a sedimentary rock, *as a rule*, contains much smaller proportions of the metals than an igneous rock,† we must conclude that these metals are not *evenly* precipitated. Yet I find it impossible to believe that all of these metals contained in the igneous rocks which have been, ever since the solid world began, going to pieces to form the enormous bulk of known sediments, can have been stored in the sea-water and are there still.

Most of the elements—especially silver, copper, iron, manganese, and gold—have been chemically detected in sea-water; but they are present only in minute traces; whereas the total amount of metals which has passed into the sea in solution during the ages of erosion and deposition must be

* C. R. Van Hise, "Principles Controlling Deposition of Ores," *Trans.*, xxx., p. 138, *et seq.*, and *The Genesis of Ore-Deposits*, p. 393.

† J. F. Kemp, "The Rôle of the Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., 174, says it appears, from analyses of both the sedimentary and the igneous rocks of Missouri for lead and zinc, that the igneous rocks are, as a rule, richer by one place of decimal than the former. F. Posepny, in *The Genesis of Ore-Deposits*, p. 122, says that innumerable analyses of marine sediments and precipitates, especially of limestones, have failed to show traces of metals.

many times in excess of the solvent power of the water at any one time, and vastly in excess of the dissolved amount now contained therein. We must, therefore, confess that, besides the metals mechanically laid down in slates and conglomerates, derived directly from the abrasion of igneous rocks, the same metals have been chemically precipitated somewhere from marine and other surface-waters. Indeed, the researches of Malaguti, Bibra and Forchhammer* long ago established the fact of such precipitation by finding traces of metals in the ashes of marine plants, and in the hard parts of marine animals, such as corals. Among the metals mentioned above as having the question of their concentration at the surface still undecided, lead, zinc, cobalt and nickel have been thus detected.

Since, therefore, the metals in question (notably lead, zinc, silver and copper), which are both relatively soluble and relatively rare, after being extracted from the igneous rocks during the process of weathering, transportation and sedimentation, have neither been uniformly deposited in the sediments nor accumulated in solution, I am forced to believe that, like the commoner elements (among them the commoner metals) already mentioned, they have been (probably by chemical precipitation) deposited in certain places as *concentrations*, which are, as a rule, relatively richer than the igneous rocks in which the said substances were originally disseminated.

The hypothesis that bedded ores have sometimes been deposited contemporaneously with the enclosing sediments has been, of late, distinctly out of fashion, and justly so, in the exclusive sense in which it has sometimes been held. Bischof, reasoning from the traces of metals in sea-water, believed that their precipitation as sulphides was possible, and thus explained the occurrences of copper and silver sulphides in the Permian *Kupferschiefer*, and of lead sulphide in the *Buntsandstein.*

Groddeck advocated the same idea, and advanced the theory that certain horizons are especially ore-bearing.† Hoefer has applied this explanation to the lead- and zinc-deposits of Upper

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* *Chem. u. Phys. Geologie*, vol. i., Bonn, 1863, pp. 445–7. C. G. Bischof.

† Posepny, *Genesis of Ore-Deposits*, first edition, p. 112, etc.; second edition, p. 122.

Silesia and other districts, which occur in Triassic marine limestone. In Bohemia and the Urals, as in the German *Kupferschiefer* district, the Permian rocks contain copper in many places; in Utah and New Mexico (in the Silver Reef and Nacimiento districts, etc.) the Triassic sandstones contain copper and sometimes silver; in the Permian of Texas there are three copper-bearing zones, extending over three counties.*

These are examples of numerous deposits which have been described by some able investigators as due to deposition contemporaneous with the enclosing beds, while, in every case, this conclusion has been repeatedly and vigorously contested. The fact is that in every one of these instances the ore-deposits have an evident genetic connection with fissures, joints, dikes, etc., of later age than the rock; and hence it is argued that the ores (including those disseminated in the rock) have been introduced through these fissures.

I need hardly point out that this conclusion is not logically valid. I confess that, after visiting the Mansfeld deposits, I was so impressed by the evident connection of the faults with the ore-bodies, and by the frequent proofs of the formation of minerals more recent than the country-rock, that I came away quite satisfied that the idea of contemporaneous deposition was old-fashioned and untenable. Yet neither there nor elsewhere does this opinion certainly follow from the observed facts. The present ore-bodies in most of these districts—perhaps in all—are largely secondary concentrations, due to percolating waters, and are hence found along water-channels, as held by Posepny and others; but this does not affect the question whether these waters brought up the metals with them "from below" or concentrated them from disseminations contemporaneous in deposition with the strata. In view of what I have stated above, I am now inclined to hold the latter view.

Among the detrital rocks, slates are known to contain marked quantities of the metals in question. Frick, Forchhammer and Sandberger found copper, zinc, lead, arsenic, antimony, tin and cobalt in clay-slates. These are, very likely, to a large extent, mechanical concentrates from the rocks by the

* Kemp, *Ore-Deposits of the United States*, third edition, p. 224, etc.

destruction of which the slates originated; yet they are probably also, in some degree, chemical precipitates.

The Mediterranean has been found to contain copper in solution in the proportion of at least 0.01 gramme to the cubic meter. Phillips* says that "the black and usually very sulphurous matter deposited in basins where sea-water has been left to itself constantly contains copper, and the same is generally true with regard to the dark-colored gypseous muds of all ages."

Most *chemically precipitated* rocks† certainly seem to be much poorer in original metallic contents than the fragmental ones. The limestones of the Mississippi valley have been shown to contain lead and zinc, disseminated in small quantity; and it is the conclusion of Whitney, Chamberlin, Winslow and others that the ore-deposits have been concentrated from these disseminations. But these limestones appear to contain the metals in smaller quantity than do the older igneous rocks of the region, so that the dissemination in the limestones can hardly be regarded as a *concentration*. (See footnote, p. 292.)

With these and other facts in mind, we cannot safely give up the idea that metals have been concentrated by surface agencies in favorable places and times, and, consequently, that certain strata (possibly also, and restrictedly, certain geologic periods) are, by reason of their original metallic contents, more favorable than others to the occurrence of ore-deposits. I would even hesitate equally to deny or to affirm that there is a connection between the Triassic and Permian red sandstones and certain copper-deposits. Yet we must be careful not to rush into any such hasty generalization as that of Sir Roderick Murchison, who believed that most auriferous rocks are of Silurian age,‡—an obsolete idea which I have nevertheless found in one of our latest works on the metallurgy of gold.§

The concentration of metals by surface agencies, though a fascinating study, is out of place in the special inquiry to which this paper is devoted—that of concentration by segregation within molten rocks.

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* Phillips and Louis, *Treatise on Ore-Deposits*, 1896, p. 132.

† This phrase is meant to include limestones of organic origin.

‡ See Rickard's "Review," *Eng. Min. Jour.*, Oct. 19, 1901, p. 491.

§ Eissler, *Metallurgy of Gold*, 1900, p. 31.

III.—The Segregation or Differentiation of Igneous Rocks.

Having pointed out the generally-admitted fact that the larger number of ore-deposits have direct genetic connection with igneous rocks, I wish to describe one of the chief processes by which the different kinds of igneous rocks originate, which I believe has an important bearing upon the segregation of ores.

While it is known that igneous rocks may be formed directly from the fusion of sediments (in which case their composition is determined by the selective action of surface agencies), yet it is now widely accepted that many, perhaps most, of them owe their peculiarities of composition to a process of segregation which goes on within the molten masses of the earth's interior. The evidence for this process, and some of the details of it, have been pretty fully stated by the writer elsewhere,* and only a few points will be mentioned here. The line of argument is best seen if we proceed from examples on a small scale to successively larger ones. Thus, in the laboratory, materials intimately mingled in solution may separate into distinct crystals, or into segregated bunches of like crystals; and in veins the different minerals are often found bunched in the same way. Nearly every igneous rock shows irregularities of composition due to a similar clustering together of like minerals. These aggregations increase from microscopic size to the size of a man's head; and from these relatively small patches there is a gradation to larger rock-masses, which have marked differences in structure and composition from the rest of the igneous body, of which they, nevertheless, form integral portions. For example, the borders of dikes are frequently less siliceous, and contain more iron (and associated elements) than the interior of the same bodies. In still larger igneous masses, it is found that different portions have slightly different chemical, mineralogical and structural characters, while they all grade into one another. Again, it has been observed that in a given district different igneous rocks (such as volcanic rocks erupted at different times) are often closely related, and pass into one another.

* "Geology of the Yukon Gold-District," 18*th Ann. Rep. U. S. Geol. Surv.* Part III., p. 300.

Finally, modern petrographic research and comparison have shown that the rocks of a large region, taken collectively, often present constant differences from those of neighboring regions.

All these phenomena may be explained by the observed fact that in the molten masses, as well as in solutions, there is a force inducing like elements to group themselves together.

Concerning the exact process by which the materials of the molten rocks are enabled to make such important migrations in order to cluster together, there is no certainty; and, indeed, for the purposes of this paper, it is hardly necessary to inquire. Until recently, it was common to appeal to Soret's principle of molecular flow, namely, that molecular concentration may be caused by differences of temperature. Mr. G. F. Becker,* however, has argued against the applicability of this law, on account of the slowness with which it operates. Mr. Becker† and the writer,‡ independently and at about the same time, called attention to the probable importance of convection currents in producing segregation. By these currents the minerals which first crystallize (namely, the heavier minerals, such as magnetite, olivine, hornblende, pyroxene, etc.) would be, to a greater or less extent, concentrated in the outer portions of igneous rock-masses, where they are actually often found.

The small segregations in igneous rock are usually either more siliceous or less siliceous (more "acid" or more "basic") than the enclosing rock; and extremely acid and extremely basic segregations are often found in close association. This tendency of the molten mass to segregate its highly siliceous constituents from the rest has also been studied on a large scale, chiefly from the order of succession of lavas erupted at successive periods in the same district, or of dikes successively introduced. Brögger and Geikie,§ from extensive studies of eruptive rocks in Norway and in Scotland, respectively, both concluded that the rocks progressed from the more basic to the more acid varieties.

* "Some Queries On Rock Differentiation," *Am. Jour. Sci.*, Jan., 1897, 4th series, vol. iii., p. 21.

† "Fractional Crystallization of Rocks," *Am. Jour. Sci.*, Oct., 1897, p. 257.

‡ "Geology of the Yukon Gold-District," 18*th Ann. Rep. U. S. Geol. Surv.*, Part III., p. 306.

§ J. P. Iddings: "The Origin of Igneous Rocks," *Bull. Phil. Soc. Wash.*, vol. xii., pp. 122, 145, 146.

Iddings's* work goes to show the normal law to be that a rock of intermediate composition is followed by rocks progressively higher and, at the same time, by others progressively lower in silica, the more basic and the more acid varieties being associated and contemporaneous; so that the series begins with a mean and ends with extremes. This has been considered by the writer to hold good for the dike-rocks of the Forty-Mile district, Alaska,† and (a problem on a much larger scale) for the petrographic province of which the great basin of Nevada forms a portion.‡ In the case of the Forty-Mile dikes, the most siliceous varieties were found to be later than the most basic ones.

The laws thus deduced agree in this: that a molten rock-mass, under favorable conditions, tends to separate (segregate) into a more acid and a more basic portion; while the fact that the acid (siliceous) rocks characteristically follow rather than precede the basic (less siliceous) at any one period, joined with the other known principles of segregation, indicates that the change is effected at each stage by the separation and crystallization of the more basic constituents, leaving the more siliceous residue unconsolidated.

That the basic minerals in general crystallize first in a cooling rock has been proved by microscopic study. If the segregation is limited in time, and is broken into by such an occurrence as eruption and consolidation, the differences attained may be comparatively slight; but under favorable circumstances extremes may be reached. Thus, rocks consisting almost entirely of olivine, pyroxene, or hornblende, together with iron oxides and sulphides, may originate. On the other hand, rocks made up essentially of quartz and alkali feldspars (alaskites)§ may be formed, and these may pass by gradual transitions into quartz-veins, as will be dwelt upon later. An illustration of these different results is found in the

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* *Op. cit.*

† "Geology of the Yukon Gold-District," *18th Ann. Rep. U. S. Geol. Surv.*, Part III., p. 234.

‡ "Succession and Relation of Lavas in the Great Basin Region," *Journal of Geology*, vol. viii., p. 621.

§ J. E. Spurr: "Classification of Igneous Rocks," *Am. Geologist*, Apr., 1900, vol. xxv., p. 229.

dikes of the Forty-Mile region,* which consist of rocks closely related, being made up chiefly of hornblende, quartz and feldspar. Yet by gradual changes in the proportions of these minerals, rocks of all degrees of basicity and acidity are produced, terminating, on the one hand, in hornblendites (composed almost entirely of hornblende) and pyroxenites, containing pyrite, pyrrhotite, ilmenite and other metallic minerals; and, on the other hand, in alaskites, growing gradually more siliceous until they pass, with no break, into quartz-veins.

In the progress of segregation, we have seen that in the acid-gaining portion there is a continuous increase of silica, due to the constant precipitation and removal of the basic portions. There is also an attendant increase in the amount of water.

As is shown by microscopic and chemical study, all rocks contain water, but the molten material contains much more than the resulting rock. Most of this water is expelled at the moment of solidification, together with certain gases and a great variety of other materials held in solution.† When rocks cool at the surface, this escaping water forms the clouds of steam, highly charged with gases and minerals, which issue from fissures and other vents; but when they solidify below the surface the waters and gases are forced into the enclosing rock, producing the recrystallization and rearrangement of its constituents, called contact-metamorphism. This is chiefly confined to the contacts of siliceous igneous rocks, being especially remarkable around intrusive masses of granite, where it occupies a zone which, in extreme cases, may be several miles in width.

It seems, therefore, that the molten material from which siliceous rocks solidify contains more water than the basic material. Therefore, we may believe that by the progressive separating out of the more basic constituents the residual portion of a molten mass becomes more aqueous and more siliceous. Thus the peculiar form (often in lenses, not visibly communicating with large bodies of igneous rocks) and coarse crystallization of pegmatites are explained; for these rocks are near the end-product of the siliceous series; and the pegmatitic

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* "Geology of the Yukon Gold-District," 18*th Ann. Rep. U. S. Geol. Surv.*, Part III., p. 233.

† Daubrée, *Géologie Expérimentale*, Paris, 1879, p. 152.

rocks, by the disappearance of feldspar and mica, grade into pure quartz-veins, which show by their structure that they have been deposited from solutions so attenuated that they may best be described as waters highly heated and charged with mineral matter in solution.

By this process of rock-differentiation concentration is continually effected, through the segregation of like materials. Most of these materials are not commercially valuable. Thus the frequent segregation of masses of nearly pure hornblende, pyroxene or quartz has no lively interest for the miner. But when (as often happens) such segregations are feldspar or mica, they may acquire economic importance. And if the commonest of rock-constituents may be thus concentrated, other substances may be, also. In the basic Forty-Mile dikes, mentioned above, there was so large a proportion of ilmenite, magnetite, pyrrhotite and other metallic minerals that small pieces of the rock were drawn by the magnet. A slight further concentration would give commercially valuable masses; and there is good evidence that, in other districts, many such masses have originated in this way.

IV. The Order of Crystallization of Minerals in Igneous Rocks.

The process of segregation, which we have considered on a large scale, with the progressive precipitation of basic ingredients and the leaving behind of the siliceous ores, is recorded on a small scale in the internal structures of igneous rocks, as studied under the microscope.

Under this head I cannot do better than quote Prof. J. F. Kemp,* who says:

"Microscopic study of the igneous rocks has shown that, with few exceptions, the rock-making minerals separate from a fused magma on cooling and crystallizing in a quite definite order.† Thus the first to form are certain oxides, magnetite, specular hematite, ilmenite, rarely chromite and picotite, a few silicates, unimportant in this connection (zircon, titanite), and the sulphides, pyrite and pyrrhotite. Next after these metallic oxides, etc., the heavy, dark-colored basic silicates, olivine, biotite, augite, and hornblende, are formed. All these minerals are characterized by high percentages of iron, magnesium, calcium and aluminum.

* *Ore-Deposits of the United States and Canada*, 4th ed., p. 33.

† H. Rosenbusch, "*Ueber das Wesen der körnigen und porphyrischen Structur bei Massengesteinen*," *Neues Jahrbuch*, 1882, ii., 1.

They are very generally provided with inclusions of the first set. Following the bisilicates in the order of crystallization come the feldspars, and after these the residual silica, which remains uncombined, separates as quartz."

V. The Formation of Mineral Segregations in Molten Masses.

It has been shown that in the process of segregation in molten masses there is a recognized tendency to split up into more siliceous and less siliceous portions. The basic materials thus concentrated may be the almost exclusive constituents of the resulting rocks. Thus there are not uncommonly rocks made up essentially of the dark, heavy, basic, ferro-magnesian minerals, biotite, olivine, pyroxene and amphibole, with metallic minerals, such as magnetite, ilmenite, etc., in smaller amounts. The acid materials likewise may form rocks without important admixture of the basic ones, as in quartz alkali-feldspar rocks (alaskite), or in rocks made up almost entirely of alkali-feldspar (sanadinite, albitite, etc.). Further, as already pointed out, the constituent minerals may separate out from the mixture and the like crystals may group themselves together. Thus, there are rocks consisting almost entirely of olivine alone (dunite), of hornblende alone (hornblendite), of pyroxene alone (pyroxenite), of orthoclase feldspar (sanadinite), of soda-feldspar (anorthosite), and of lime-feldspar (anorthite rock). This completes the roll of the commonest rock constituents, save the micas and quartz. Although mica forms small segregations in igneous rocks, the writer is not aware that it occurs as the only essential mineral in any considerable mass of such rock. Quartz also appears at first sight to be an exception; but the writer will try to show later that this is not so, and that many considerable masses and veins of quartz are the result of segregation from the same molten material that produces other igneous rocks.

Besides these commonest original or primary minerals, there are others which are commonly present in marked quantity in almost every fragment of igneous rock. Perhaps the most important of these is magnetite, which is found in nearly all rocks. Besides this, there are other common metallic minerals, such as pyrite, ilmenite and pyrrhotite—all iron minerals. Chromite is rarer. Among the non-metallic accessory min-

erals, zircon, titanite and apatite are perhaps the most important. All of these less common minerals (as well as others not mentioned) are known to segregate, to a certain extent at least, so that they are many times more abundant in some rocks than in others.

This being the case, it is natural that the still rarer minerals and elements should also segregate, and should be found in certain rocks in far larger quantity than in others; and, indeed, this is known to be the fact.

VI. The Unknown Finer Laws of Rock-Segregation.

If there were invariable associations between certain rocks and certain valuable minerals, prospectors and miners would probably have detected it long ago, especially as regards the metals. But in the majority of cases the exceptions, to any rule we may be tempted to construct, are so numerous that we abandon the attempt. That this fact, however, does not contradict the conclusions above reached in regard to the preferential segregation of these minerals into certain rocks will appear when we consider how we name and distinguish the rocks themselves. The existing classifications of rocks are all based upon the relative content of the common constituents, the rarer ones being necessarily disregarded. The divisions, granite, syenite, dunite, diabase, basalt, phonolite, and the whole legion of others, are (apart from considerations of structure, age, mode of occurrence, etc., which have for the moment no bearing on this discussion) founded upon the presence and relative proportions of the ordinary minerals quartz, the various feldspars and feldspathoids, olivine, mica, amphibole and pyroxene. Even in classifications based upon the chemical composition of the whole rock, the component minerals being lumped together for analysis, only certain ordinary elements are taken into account, and the rock is assigned to its place upon the basis of the relative proportions of silicon, aluminum, iron, calcium, magnesium, sodium and potassium. Rock-divisions based on these elements do not necessarily connote the presence or absence of any others. For example, a petrographer finding a certain igneous rock, knows at once that this rock is unusually rich in calcium, sodium, aluminum or silicon; but he does not know if it contains more or less than the average quantity of lead,

silver or mercury. Each element follows its own independent law of segregation, and disregards the established rock-classification. Even with the commoner minerals and elements upon which this classification is roughly based, the variations are so wide as to lead the petrographer into grave difficulties. Thus, among the rocks which have been called *gabbro* we may find some consisting almost entirely of feldspar, and others made up chiefly of pyroxene. One of the commonest chemical divisions of the rocks is into acid, basic and intermediate kinds, essentially according to the proportion of silica present; but rocks of different mineralogical composition may have the same acidity. The basic rocks are rich in ferro-magnesian silicates, and so should be exceptionally strong in magnesia; but occasionally cases may be found where gabbro shows less magnesia than granite.

We can hardly expect, therefore, that the identification of a rock-species, under the accepted classification, will be of much help in guiding us to a knowledge of the relative content of the rarer elements. To arrive at such a knowledge, we should have a classification based principally upon the content of these rarer elements, and recognizable in practice by easy physical and chemical marks. But this is clearly impracticable.

In this difficulty, we may be helped to some extent by the principle which underlies the laws of chemical affinity and the association of minerals. Elements and minerals have tendencies to cluster in groups marked by some common characteristics; each element or mineral prefers to associate with certain elements or minerals rather than with others. This law of selective association has long been recognized by the geologist and the chemist. So it seems reasonable that among the rare elements and minerals not considered in rock-classification, some may have such strong preferential association with certain of the commoner rock-constituents on which this classification is based that we may be able to see some connection, even if a rude one, between these rarer constituents and the established rock-types.

VII. The Presence of Metals in the Igneous Rocks.

Iron is present—often in high percentage—in nearly every igneous rock. It occurs not only in the dark ferro-magnesian

silicates, but also as oxides and sulphides, as hematite, magnetite, ilmenite, pyrite and pyrrhotite.

Chromium, in the form of chromite and picotite, chrome-diopside, etc., occurs in marked quantities as an original constituent of many basic igneous rocks. Manganese is present in nearly every igneous rock, as a not unimportant constituent of the ferro-magnesian silicates. The rarer metals, lead, copper, zinc, tin, antimony, arsenic, nickel, cobalt, silver, gold, and the still rarer ones, have all been repeatedly found in fresh igneous rocks, particularly in the dark bisilicates.

VIII. The Concentration of Commercially-Valuable Minerals by Segregation within Molten Masses, Previous to their Consolidation.

1. *Iron.*

The fact that iron is unequally distributed in igneous rocks is well known. Many highly siliceous rocks (acid granites, alaskites, etc.) have only a trifling quantity (often 1 per cent. or less), while the basic rocks may contain 10, 15, and even 20 per cent. of iron oxide. Of this iron, a part is generally in the form of magnetite, a mineral shown by the microscope to be thickly disseminated in many basic rocks. It is generally titaniferous, and grades into ilmenite. From the highly magnetiferous phases of ordinary basic rocks to a phase where the magnetite becomes the principal constituent is an easy step. Such are the occurrences at Cumberland, Rhode Island, at Taberg, in Sweden, and in many other places. At some of these localities the iron mineral may gradually increase so as to almost exclude the other constituents, as at Taberg; or it may quite do so, as in the anorthosites of Minnesota and elsewhere, forming masses of iron-ore. As to the origin of these ores by segregation within the molten masses previous to cooling, there is a practical unanimity of opinion.

2. *Chromium.*

Like iron, chromium has a very manifest uneven distribution in igneous rocks, being rare in the siliceous ones, while in many of the basic ones it forms a not insignificant constituent, especially in rocks containing olivine.* In these rocks its relations

* Zirkel, *Lehrbuch der Petrographie*, 2d ed., vol. i., p. 426.

to other minerals show that, like magnetite, it is one of the earliest to crystallize during consolidation. That the chromite may, in some portions of these rocks, become so abundant as to form the principal constituent, the rock being nevertheless in nearly the state in which it cooled from fusion, is an occurrence which we might expect from our knowledge of the selective segregation of other constituents, and one which has been repeatedly observed. Vogt* has described a fresh peridotite from Norway which was almost or quite rich enough in chromite to be worthy of exploitation. The most important occurrences of chrome-ore occur in serpentines, which can generally be shown to be the product of decomposition of basic igneous rocks, chiefly peridotites (olivine rocks); and these deposits are considered by Vogt to be the result of segregation while the mass was molten (magmatic segregation), although they had been explained by others as due to after-actions which took place during the alteration of the fresh rock to serpentine, or even to pneumatolytic (vaporous) action at the time of the rock's consolidation. J. H. Pratt, after studying the chrome-ores of North Carolina, arrived at the same conclusion as Vogt for other regions, namely, that the ores were actually magmatic segregations. Kemp† favors the same origin for other chromite-deposits in the United States. The writer, after examining the chromite-deposits near Saloniki, Turkey (Macedonia), and also in Asia Minor, inclines to the belief that most of these deposits have originated as magmatic segregations from the enclosing peridotitic rock.

3. *Nickel.*

Nickel occurs as an original constituent of some olivines‡ in basic igneous rocks. It is also found in more considerable amount in pyrrhotite, a sulphide of iron which is frequently a primary mineral in igneous rocks and one of the first to crystallize on consolidation. Nickel occurs also as an alloy with native iron, in meteorites and in basalt.

In certain igneous rocks—as, for example, in the peridotites of Douglas county, Oregon, and of Webster, North Carolina—nickel is much more abundant than in others of the same petro-

* Quoted by J. F. Kemp, *Ore-Deposits of the U. S. and Canada*, 4th ed., p. 413.
† *Op. cit.*, p. 415. ‡ Dana, *System of Mineralogy*, 6th ed., p. 453.

graphical character. In the instances named, the nickel, upon the weathering of the rock, separated out as nickel silicate, and became concentrated sufficiently to be of possible economic importance.

Although these ore-deposits are immediately due to circulating surface-waters, which have accomplished a second concentration, the first and most important concentration was that which brought together unusual quantities of nickel in these particular rocks, and this was plainly done by magmatic segregation.

It has already been noted that pyrrhotite, like the other early crystallizing metallic minerals, may become abundant as a primary constituent of igneous rocks—as, for example, in the case of the Forty-Mile creek dike, already mentioned.* Cases where niccoliferous pyrrhotite in basic igneous rocks, evidently a primary constituent, gradually increases so as to form compact masses and to become a valuable ore, have been described on the best authority.

Of such origin (partly, at least) seem to be the niccoliferous pyrrhotites of Sudbury, Ontario, and those of the Gap mine, Lancaster, Pennsylvania.†

4. *Cobalt.*

This metal has the closest associations with nickel, and the general conclusions arrived at for the one are probably to a considerable degree good for the other. Like nickel, cobalt is present in perceptible quantity in certain basic igneous rocks, where it has been identified as occurring in olivine,‡ and, alloyed with native iron, nickel and copper, in Greenland basalt.

As yet, however, we have not sufficient reliable data to determine whether any important cobalt-ores are formed *principally* by magmatic segregation.

5. *Platinum.*

Platinum, in perhaps the majority of cases, is found closely associated with chromite or nickel, or both. Like these minerals, it is almost invariably genetically connected with basic

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* See p. 300.

† J. F. Kemp, *Ore-Deposits of the United States and Canada*, 4th ed., p. 431.

‡ Dana, *System of Mineralogy*, 6th ed., p. 453.

olivine rocks, or with the serpentine-rocks arising from the alteration of these. As an original constituent in basic igneous rocks, it is said to have been found by both Daubrée and Engelhardt. More recently, native platinum has been discovered in igneous rocks in the Urals, in the Nizhni-Tagil district, and the Goroblagodat district. These are extremely basic peridotitic rocks, containing large amounts of magnetite and chromite, besides platinum. According to Inostranzeff, the platinum occurs as grains and leaves in the chromite. In the Goroblagodat district, while the peridotites contain by far the larger amount of platinum, Saytzeff found the metal as an original constituent in other igneous rocks also, such as porphyrite, gabbro-diorite, and syenite-gneiss. Mr. C. W. Purington also obtained, on crushing and panning the peridotite of this district, many fine colors of platinum.* The writer has also had the privilege of visiting the district, and of collecting some of the platinum-bearing peridotite.

The Ural occurrence, both by reason of the presence of the platinum disseminated in basic igneous rocks and its connection with chromite and magnetite of acknowledged igneous origin, must be admitted to be a product of magmatic segregation; and how powerful this segregation has been we learn from the fact that assays of the ferrous blebs (the most basic segregations) in the Nizhni-Tagil rocks gave a figure corresponding to $50 per ton.†

That in this region the platinum has been remarkably concentrated, as compared with similar rocks in other places, is shown by the observation of Saytzeff that even rocks elsewhere not known to be platiniferous—"porphyrite, gabbro-diorite and syenite-gneiss"—contain it.‡

6. *Copper.*

Copper, as an original constituent, is known to enter into the composition of the dark ferro-magnesian silicates of the igneous rocks. It occurs also in meteorites, and, alloyed with

* C. W. Purington, "Platinum Deposits of the Tura River-System," *Trans.*, xxix., p. 8.

† Purington, *op. cit.*, p. 8.

‡ A note in the *Eng. and Min. Jour.*, November 16, 1901, p. 632, says that samples of rock from the State of Washington contain, according to Prof. J. F. Kemp, from 0.375 to 0.5 oz. of platinum per ton. The nature of the rock is not stated.

native iron, in the Ovifak (Greenland) basalt. The segregations of pyrrhotite before noted in connection with nickel, and believed to have formed in the distinctly ante-consolidation period, are frequently cupriferous, and even contain copper pyrites, as at Sudbury, Ontario. The magmatic segregation of the pyrrhotite being granted, the copper also has probably been chiefly concentrated in the same way.*

According to some observers, even high-grade copper-ores in various districts have had this origin.†

7. *Gold.*

Pyrrhotite frequently, and chalcopyrite generally, contains gold. Some masses of auriferous pyrrhotite and chalcopyrite have been thought to have originated like the niccoliferous pyrrhotite above mentioned. Such is the case at Rossland, B. C., where the ores have been considered by many writers to be magmatic segregations, while other observers, equally reliable, believe them to be secondary replacement deposits or fissure-veins. The hypothesis of a first concentration by magmatic segregation and a second by circulating waters may possibly be the key to the problem.

Native gold, probably as an original constituent, has been found in granite,‡ in eurite§ (alaskite), in quartz-trachyte,‖ and in gabbro.¶

IX. The Origin of Certain Gold-Quartz Veins.

As remarked in the preceding paragraph, native gold has been found in both basic and acid rocks. It has also been detected in the dark ferro-magnesian silicates of rocks of all degrees of acidity. The commercially-valuable concentrations of gold are generally connected, now with basalt or gabbro, now with diorite, now with phonolite, rhyolite, or granite. They occur also in many different forms, as replacement-de-

* J. F. Kemp, *Ore-Deposits of the U. S. and Canada*, 4th ed., pp. 436–7.

† Vogt, "Problems in the Geology of Ore-Deposits," *Trans.*, xxxi., p. 131. *Genesis of Ore-Deposits*, p. 642.

‡ G. P. Merrill, *Am. Jour. Sci.*, April, 1896, 4th series, vol. i., p. 309.

§ G. W. Card, *Records Geol. Surveys of N. S. W.*, 1895, p. 154.

‖ W. Möricke, *Tschermak, Min. Mitth.*, xii., p. 195.

¶ Cited by J. F. Kemp, *Ore-Deposits of the United States and Canada*, 4th ed., p. 36.

posits in limestone; as disseminations in igneous and sedimentary rocks; as contact-deposits near intrusive masses; and in fissure-veins. Most of the known processes by which ore-deposits are found have probably been active in producing gold-ores. A possible case of origin by segregation in a basic magma has just been noted (at Rossland). But the writer believes that most frequently the metal is concentrated in siliceous magmas.

After studying the Yukon gold-quartz veins in 1896–7, the writer announced a theory of their formation as the end-product of rock-segregation in the region where they occur.* In this connection a brief outline of the theory will be given, with a few additional observations, since made, which tend to strengthen it.

Under a previous heading, in considering the segregation (differentiation) of igneous rocks, the conclusion has been reached that many magmas segregate by a repeated concentration and consolidation of the basic constituents, leaving a more siliceous residue.

Just as this process may result in rocks of extreme basicity, such as olivine, hornblende and augite rocks, and even in segregated masses of the metallic minerals which ordinarily are accessory constituents, so, at the other end of the series, very siliceous rocks arise. From the siliceous granites the transition is gradual (and may often be observed in a single rock-mass) to more siliceous rocks, consisting almost entirely of quartz and alkali-feldspar without important admixture of the dark ferro-magnesian minerals.

These rocks are regarded by the writer as far more wide-spread and important than has generally been recognized, and to the group he has applied the general term "alaskite."† These alaskites may pass gradually into quartz-veins.

In the multitudinous and varied dike-rocks of Forty-Mile creek, Alaska, where most of the observations were made which led up to the theory in question, every stage in the increasing acidity was observed.‡ The rocks which here occur

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* J. E. Spurr, "Geology of the Yukon Gold-District," *18th Ann. Rept. U. S. Geol. Surv.*, Part III., p. 312.

† J. E. Spurr, "Classification of Igneous Rocks," *Am. Geologist*, April, 1900, p. 229.

‡ J. E. Spurr, "Geology of the Yukon Gold-District," *18th Ann. Rept. U. S. Geol. Survey*, Part III., p. 232.

in greatest bulk are hornblende granites and hornblende diorites, both of medium acidity. From these rocks the change is very gradual to the extremely basic rocks before mentioned. We will, however, not dwell on this phase of the segregation, but turn to the development of the siliceous rocks, which is equally well displayed.

The basic hornblende granite, which forms the greatest rock masses, contains subordinate quantities of biotite. By a very gradual transition the hornblende diminishes in amount as the proportion of biotite increases, so that the rock becomes a biotite-granite; and in many dikes the amount of biotite becomes less and less, giving rise to an extremely siliceous granite, in which the biotite is an insignificant constituent as compared with the quartz and feldspar. With further diminution of the biotite the granites change into essentially quartz-alkali feldspar rocks—alaskites. These rocks are sometimes fine-grained, or may be coarse, like granites, but have a nearly uniform structure and composition. In the alaskite series the change is continued by a relative increase in amount of quartz and decrease of feldspar. One remarkable phase studied is a porphyritic dike rock whose ground-mass consists almost entirely of quartz in small interlocking grains, giving, both in the hand-specimen and under the microscope, the exact appearance of a quartzite. Yet this rock contains scattered but regularly distributed porphyritic crystals of feldspar. It is thus not only related by the closest ties to similar slightly less siliceous alaskites of the same district, but it is only removed by its scattered porphyritic crystals from being a typical quartz-vein. Moreover, the superabundant quartz in these very siliceous dikes tends to segregate into bunches, which may become large, and which have all the characteristics of ordinary vein-quartz. With the progressive increase in silicification the quartz begins to occupy an important portion, and finally the larger portion, of the dike. The feldspar becomes restricted to certain places, sometimes occurring irregularly, sometimes collecting near the walls, while the quartz lies in the center.*

* This distribution is in accordance with the theory of segregation by the aid of convection currents ("Yukon Gold-District," 18*th Ann. Rep. U. S. Geol. Surv.*, Part III., p. 306), by which the least siliceous and first-precipitated minerals are concentrated near the cooler dike-walls.

Finally, by the disappearance of the feldspar, the dike becomes an ordinary quartz-vein.

In one and the same dike the change from a coarse alaskite to a typical quartz-vein may be seen in all its stages.

The quartz-veins generally contain pyrites, as do all the other dikes of the region; they contain occasional biotite, and some segregated calcite, as do also the coarse alaskites. It may be remarked, in connection with the calcite, that epidote, the silicate of lime, aluminum and iron, is a constant and important mineral in all the rocks of the Forty-Mile region, from the hornblendites and pyroxenites to the most siliceous alaskites.

These veins contain pyrite, argentiferous galena, and free gold. From them a portion of the Yukon placer-gold is probably derived, much of the remainder coming from older quartz-veins which, by reason of the shearing and metamorphosis they have undergone, do not offer plain evidence as to their origin.

Therefore it has been concluded that certain quartz-veins in the Yukon district (part, at least, of which are auriferous) have originated by a process of magmatic segregation, which has separated them from other materials while in a state of aqueo-igneous fusion (the condition of molten rock in general), and that they represent the siliceous extreme of that process. From this standpoint, they are a variety of the igneous rocks. But it has been shown that as magmas become more siliceous they also contain more water; so, when the stage of quartz-veins is reached, the magma is believed to be so attenuated that it may best be described as water highly heated and heavily charged with mineral matter in solution. There would thus be no great difference (save in their associations, and very likely in the selection of the mineral matters which they contain) between these solutions and others where the water may have had, say, an atmospheric origin; and a quartz-vein originating by magmatic segregation might often not be distinguishable from one formed in the many other ways which are possible. The main point of interest, so far as this discussion is concerned, is, as the writer believes, that veins originating by magmatic segregation are especially apt to contain gold (without the admixture of so great proportions of the commoner metals as is usual in ore-deposits), and that thus an important class of typical gold-quartz veins has been formed.

Having briefly stated the evidence and formulated the theory for the Yukon district, let us recite some of the evidence bearing on it elsewhere.

1. *Evidence as to the Origin of Quartz-Veins as Magmatic Segregations.*

Pegmatites are coarsely crystalline rocks which show close relationships with ordinary igneous rocks, such as granites, on the one hand, and with *veins*, such as are known to be due to precipitation from aqueous solution, on the other. Hence there has been much perplexity and contention, some referring them to the "igneous" rocks and calling them *dikes*, others insisting that they were "aqueous" and true *veins*. But the latest and best essays on the subject* agree that pegmatites are formed under conditions *intermediate* between those which govern the formation of siliceous "igneous" rocks like granite, and those under which quartz-veins are formed. There is, in short, no line of demarcation in nature, corresponding to our artificial and arbitrary one, between igneous rocks and certain aqueous veins—between granites and certain large masses of quartz.

Transitions of pegmatite- to quartz-veins, showing absolute and uniform gradation from one to the other, have been noted by Crosby and Fuller, Williams† and Van Hise,‡ and transitions or evident close and constant relations between pegmatites and granites have been noted by Crosby, Brögger, Van Hise and Williams.

Professor C. W. Hall§ has furnished notes on Eastern and Central Minnesota, where, in connection with intrusions of hornblende-biotite granite, are shown "granitic veins." These are "locally pegmatitic, with coarse and well-developed feldspar individuals imbedded in a matrix of hornblende and biotite, while elsewhere they are finely textured, possess a reddish

* "Origin of Pegmatite," by W. O. Crosby and M. L. Fuller, *Amer. Geologist*, vol. xix. (1897), p. 147; "*Die Mineralien der Syenit-pegmatitgänge der südnorwegischen Augit- und Nephelin-syenite*," by W. C. Brögger, *Zeitsch. für Kryst.*, vol. xvi., 1890, pp. 215–235. "Origin of the Maryland Pegmatites," by G. H. Williams, *15th Ann. Report U. S. Geol. Sur.*, 1895, p. 675. † *Op cit.*, p. 679.

‡ *16th Ann. Report U. S. Geol. Sur.*, Part I., 1896, p. 688.

§ Keewatin Area of Eastern and Central Minnesota, *Bull. Geol. Soc. Amer.*, vol. xii., pp. 367–8–9 (1901).

color, and are highly siliceous in composition." Associated with these are veins of quartz. In the St. Louis river-district the veins, when wide, become pegmatitic. The veins sometimes carry segregated sulphides and siderite. One, on Kettle river, has been explored for gold.

Professor J. F. Kemp* observes that on the north shore of Long Island Sound "pegmatites are abundantly developed in connection with granites, and all grades are shown up to practically pure quartz." One of the largest quartz-veins, which Professor Kemp thinks belongs to the pegmatitic series, carries, in portions, ferruginous minerals and traces of gold.

Dr. E. Hussak† has described an auriferous quartz-vein in Brazil which he regards as an ultra-acid granitic dike. Mr. Waldemar Lindgren, however, dissents from this conclusion.‡

According to Phillips and Louis,§ at Timbarra, in New South Wales, "gold is found in granite; these gold-fields consist of a granitic tableland, traversed by dikes of eurite|| and pegmatite, also occasionally showing veins of auriferous quartz, which may possibly be segregation deposits."

At Silver Peak, Nevada, the writer noticed transitions from the granitic rock (which is there intrusive in Cambrian limestones) into quartz-veins. Mr. H. W. Turner, who studied this region more in detail, made the same observation independently, and communicated it subsequently to the writer. According to him, these segregated veins seem to be connected in some way with the Silver Peak ore-deposits, which are gold-quartz veins.

On the Mojave river, in Southern California, the writer observed one of the most rapid and complete transitions from quartz-veins into granite which he has ever seen. Here Paleozoic limestones and quartzites (considerably metamorphosed) are cut by intrusive granite, whose dikes grade into pegmatite, and these to quartz-veins. In a single dike he observed, within the length of not many yards, a complete transition from a

* "The Rôle of the Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., p. 182. *Genesis of Ore-Deposits*, p. 693.

† *Zeitschrift für prakt. Geologie*, 1898, p. 345.

‡ "Metasomatic Processes in Fissure-Veins," *Trans.*, xxx., 642, and *Genesis of Ore-Deposits*, p. 562.

§ *Ore-Deposits*, second edition p. 649.

|| Alaskite.—J. E. S.

fine-grained pegmatite to a typical quartz-vein. Gold is found in this locality (Oro Grande), but, unfortunately, he did not remain long enough to find whether it is in these quartz-veins.

The writer has also studied the transition of granite and alaskite through pegmatitic stages to quartz-veins, in the Walker river range, in northwestern Nevada, near the Indian reservation; and again in the Mojave desert, southeast of Randeburg, California.

At Belmont, in Nevada, the writer has made a brief study of an interesting dike-rock and its associated phenomena.* The dike is one of the outlying offshoots from a large body of siliceous granite; it is nearly half a mile wide, and cuts Silurian slates and limestones. Near the contact the slates and limestones have been transformed into jasperoid† by the introduction of silica; in part they have also been altered to micaceous schists, often containing disseminated small bundles of yellow and red metallic oxides. In this rock occur quartz-veins which carry rich antimonial silver-ores.

The dike-rock varies greatly in texture and composition. One specimen collected, classed as a siliceous muscovite-biotite granite, is remarkable for the irregular arrangement of its constituent minerals, the quartz often segregating into bunches a quarter of an inch in diameter, with all the characteristics of vein-quartz. A coarser-grained biotite granite at some little distance has the same peculiarity, and in this place the blotches of quartz, mosaics of intergrown grains, are from one-third of an inch to one-half an inch in diameter. But the rock of chief interest is one which looks like a micaceous quartzite, and, indeed, consists essentially of muscovite and quartz. Microscopic stŭdy reveals it in the presence of the feldspar albite, and proves that the muscovite has largely been derived from the alteration of orthoclase. Yet the rock is fresh and hard, and the change has not been affected by surface weathering.

"The process must be regarded as one of endomorphism, and as connected and probably contemporaneous with the exomorphism indicated by the alteration of the siliceous limestone of the wall-rocks to jasperoid and mica schist.

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* J. E. Spurr, *Am. J. Sci.*, 4th series, vol. x., p. 351 (1900): "Quartz-Muscovite Rock from Belmont, Nev., the Equivalent of the Russian Beresite."

† J. E. Spurr, "Geology of Aspen District," Mon. xxxi., *U. S. G. S.*, p. 219.

"In both the intrusive and the intruded rock the result of the metamorphism has been the same, producing quartz and muscovite at the expense of the orthoclase on the one hand, and of the calcite and subordinate minerals on the other. In the case of the wall-rock the metamorphism, being apparently, from its distribution, dependent upon the intrusion, evidently took place after this intrusion, and was brought about by the solutions which accompanied the igneous rock, or were residual from its solidification. Within the dike the similar alteration was probably contemporaneous with that in the country-rock."*

White quartz-veins, often several feet in width, occur in the immediate vicinity of this intrusive mass. For these the conclusion is reached that:

"These quartz-veins are probably contemporaneous with those already described as occurring in irregular form within the dike-rock itself, and as evidently representing the final product of the residual solution of the general magma. In these quartz-veins† the metallic minerals [chiefly stetefeldtite, an argentiferous ore of antimony, with some lead, copper and iron] are scattered in bunches or disseminated particles, rarely in banded form. . . . .

"The metallic minerals being, from their habit, plainly contemporaneous with the quartz-veins which enclose them, it is evident that the deposition of these minerals, the formation of the quartz-veins, the metamorphism of the country-rock to jasperoid and muscovite schist, and the endomorphism of the muscovite-granite to quartz-muscovite rock were contemporaneous occurrences, all brought about by the same agencies, which were the solutions representing the end-product of the differentiation of the granitic intrusive rock."

This Belmont quartz-muscovite rock acquires additional interest as the equivalent of the so-called *beresite* of the Urals, which the writer has had the privilege of studying in the field. After considerable investigation and discussion, the Ural beresite (composed of quartz and muscovite) has been shown by Arzruni to be an alteration from a muscovite-granite in the same way as the Belmont rock. The analogy between the Belmont phenomena and those of Berezovsk is still more striking when we consider the close connection of the beresite with gold-quartz veins. This rock forms intrusive dikes from 2 to 40 meters wide, cutting schists. Previous to all scientific investigation, these dikes were recognized by the miners as the surest guides to gold. The auriferous veins are found in the dikes, and only rarely extend into the country-rock. They generally stretch across the dikes at right angles to the walls, and have been considered as filling "fissures of contraction" by

* *Op. cit.*, p. 355.

† According to S. F. Emmons, "Geol. Expl. of 40th Parallel," vol. iii. (Mining Industry), p. 398.

Posepny.* This is probably correct, for the veins follow the same lines as the "columnar jointing" of dikes, which are due to contraction.

At Belmont the important point in determining the age of the quartz-veins is their contemporaneity with the contact-metamorphosis of the wall-rocks, which fixes their period of formation as during the final stage of the consolidation of the granite. We have not sufficient data to announce this same criterion for Berezovsk, and in the study of ore-deposits one must ever beware of reasoning too closely from analogy; but the fact that the "beresite" has, like the Belmont quartz-muscovite rock, originated not by surface alteration, but through deeper-seated solutions,† that this alteration seems a part of that which produced the gold-quartz veins,‡ and that the latter are confined to the dikes or their immediate vicinity,—all these are in favor of the hypothesis of the origin of the veins as the last and most siliceous and most fluid segregation product of the granitic magma.

2. *The Genetic Connection of Gold-Quartz Veins with Siliceous Igneous Rocks.*

We have reviewed a number of cases of the actually observed transition from siliceous igneous rocks to quartz-veins, with or without a pegmatite stage, and in most of these the veins contain disseminated metals, notably gold. When mining engineers and geologists begin to look more carefully for such transitions, it is probable that numerous others will be found. Meantime, the number of instances in which gold-quartz veins are intimately associated with siliceous intrusive rocks is really remarkable.

On the Pelly river, in British Columbia (a part of the Yukon gold-belt), Dr. G. M. Dawson§ found evidence to show that the development of quartz-veins had occurred contemporaneously with the upheaval of the granites, and probably by some action superinduced by the granite masses themselves while still in a formative condition.

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* *Genesis of Ore-Deposits,* first edition, p. 70; second edition, p. 76.

† The beresite is deeply decomposed by surface agencies, but this is independent of the agency by which the first rock originated.

‡ The beresite itself contains gold in small quantity (50 drachms to the ton).

§ *Ann. Rep. Geol. Nat. Hist. Survey,* Canada, vol. iii., Part I., p. 35 B.

In the Cook Inlet region, Alaska, gold is found in aplite* dikes, according to Mr. W. C. Mendenhall. In the Nome region, Messrs. Schrader and Brooks† report veins containing sulphides, quartz and calcite, cutting metamorphic marble and schists. A large area of granite is also reported.

In the Slocan District, British Columbia, according to W. A. Carlyle,‡ the typical gold-quartz veins, as well as quartz-veins carrying argentite, native silver and gold, appears to be confined to granite, while veins containing argentiferous galena, blende, siderite, tetrahedrite, etc., are found both in stratified rocks and granites. In California, Whitney§ noted that, while the granite itself is not metalliferous, its appearance seems to be closely associated with the metamorphism of the adjacent sedimentary rocks, while this latter condition is, as a general rule, the concomitant of the occurrence of minerals or metalliferous veins. Prof. J. F. Kemp‖ remarks: "The enormous introduction of silica is one of the most extraordinary features of the geology of the Sierras, and indicates a remarkable activity of circulating waters. The igneous intrusions doubtless promoted, if they did not cause, the circulations." In the Lake of the Woods district, schists, early granite, and gneiss are cut by later granite. The veins are found in the schists, but favor the portions near the contact with the granite or gneiss.¶

In the gold-bearing region of Nova Scotia, metamorphosed sedimentary rocks containing quartz-veins are cut by many great intrusions of granite.**

In Madison county, Montana, gold-quartz veins occur in granite; in Beaverhead county, at the contact between limestone and granite; in Lewis and Clarke county, in granite and slates, etc.††

In Rhode Island, quartz-veins are frequent around the great inclusions of granite. Traces of gold have been met.‡‡

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* "Alaskite."—J. E. S.

† *Trans.*, xxx., p. 238.

‡ Quoted by J. F. Kemp, *Ore-Deposits of the United States and Canada*, 4th ed., p. 395.

§ *The Auriferous Gravels of the Sierra Nevada*, p. 353.

‖ *Ore-Deposits of the United States and Canada*, 4th ed., p. 370.

¶ Kemp, *op. cit.*, p. 385.

** Kemp, *op. cit.*, p. 397.

†† Kemp, *op. cit.*, p. 320.

‡‡ Kemp, *op. cit.*, p. 383.

In the Appalachian gold-quartz region are numerous intrusions of granitic rocks, and pegmatite is abundant.*

In British Guiana, gold-quartz veins "occur mostly in metamorphic schists and gneiss; and nearly all the streams and rivers that traverse regions occupied by the above rocks, or by granite, are gold-bearing."†

In the Sutherland gold-fields in Scotland, the rocks are granites, gneiss, mica-schist, and quartzite, and, in a few localities only, quartz-veins. On the stream called the Kildonan, "the miners preferred working either in the vicinity of masses of granite, or in the neighborhood of a partially decomposed greenish schist."

No gold has been found *in situ* in this district, but the drift is entirely composed of fragments of purely local rocks, while quartz pebbles are almost entirely wanting.

Influenced by these and similar considerations, Messrs. Joass and Cameron are disposed to ascribe a granitic origin to the gold of this area.‡

On the island of Bömmel, in Norway, the chief country-rock is "gabbro," in which large dikes of "quartz-porphyry," passing into granite, and of altered diorite, occur; on the south of the district is a large tract of slate, in which are non-auriferous quartz-veins. The "quartz-porphyry" dikes, and those of diorite, contain strong gold-quartz veins, whose general contemporaneity with the period of igneous intrusion is shown by their being older than some dikes and younger than others.§

In the Kotchkar district, in the Urals, the gold-quartz veins, as seen by the writer on the occasion of a brief visit, are immediately the results of circulating waters subsequent to the consolidation of the country-rock; but they occur in and are probably primarily dependent upon the granite. There are analogies in many ways between this district and that of Monte Cristo, Washington State, U. S. A., where, according to the writer's study, the ore-deposits (chiefly replacements of igneous rocks by auriferous sulphides), while immediately the work of ordinary circulating waters, yet are closely dependent upon

* Phillips and Louis, *Ore-Deposits*, 2d ed., pp. 786–7.

† Phillips and Louis, *op. cit.*, pp. 887, 888.

‡ Phillips and Louis, *op. cit.*, p. 320.

§ Phillips and Louis, *op. cit.*, p. 519.

great intrusive bodies of tonalite in which the *first concentration* has probably been effected by magmatic segregation.

In India, it has been stated by Mr. King that the so-called quartz-reefs of the Travancore State "are not really veins, but merely the outcrops of beds of quartzite, associated with feldspar, which run with the foliations of the gneiss. Although minute traces of gold may sometimes be detected in these rocks by assay, the amount present is far too small to render them of any commercial value as a source of that metal." The phrase "beds of quartzite, associated with feldspar," strongly suggests fine-grained siliceous alaskite dikes. In the Wynaad district, "the gold-bearing area consists of granite, gneiss, and various metamorphic rocks, traversed by veins of quartz, which, with their branches, are auriferous."*

In China, the reported gold-quartz veins occur almost entirely in granite, as at Ninghai, the Chao-Yuen district, and Yeshui in Mongolia.†

In Siberia, the connection of the gold with granite and granitite‡ has been observed in more than one place.§

Turning to Australia, we find a relation of the gold to siliceous igneous rocks quite as striking as in California and Alaska. In Victoria,

"Gold is not only found in veins traversing granite, felsite and diorite, but is also sometimes disseminated throughout the rocks themselves."‖

I quote from Phillips and Louis:¶

"In a paper read before the Geological Society of London in April, 1872, Mr. Richard Daintree drew attention to the fact that the auriferous Devonian districts of Queensland are entirely confined to such as are penetrated by certain eruptive rocks, principally pyritous diorites. In these diorites, and near the point of their intersection with the Devonian strata, veins of quartz, calc-spar and iron-pyrites had been examined and found rich in gold, while the extensions of such veins at any considerable distance from the intrusive rocks were found to be barren. Instances were also adduced to show that the pyrites sporadically distributed through the diorites was occasionally distinctly auriferous, and had, by its decomposition and disintegration, produced drifts containing gold in paying quantities.

"In a subsequent communication, Mr. Daintree states that since the date of

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* Phillips and Louis, *Ore-Deposits*, pp. 562–3.

† Phillips and Louis, *op. cit.*, p. 618.

‡ "Alaskite."—J. E. S.

§ Quoted by De Launay, "Contribution à l'Étude des Gîtes Métallifères," *Annales d. Mines*, August, 1897, 9th series, vol. xii., p. 224.

‖ Phillips and Louis, *Ore-Deposits*, p. 620.

¶ *Op cit.*, p. 641–2.

his first paper he had learned from Mr. C. Wilkinson, then Government Geologist of New South Wales, that the same facts hold good for the New South Wales gold-fields lying in Upper Silurian or Devonian areas; and Mr. G. H. F. Ulrich, the Curator of the Technological Museum in Melbourne, in his catalogue of the rocks in that institution, gives details which go to show that the Upper Silurian rocks of Victoria owe their auriferous character to the same cause.

"He describes the diorites of Victoria as occurring mostly as dikes, varying in thickness from a few feet to several hundred, traversing Upper Silurian strata, and presenting nearly all the ordinary varieties of structure and composition of that rock. They are nearly always impregnated with auriferous pyrites, and are either traversed by or associated with quartz-veins. According to Mr. Ulrich, by far the greater proportion of the quartz-gold furnished by the gold-fields occupied by Upper Silurian rocks is derived from dikes of diorite. . . .

"The question as to when the auriferous pyrites was deposited in these diorites is of much interest, and one that it will be somewhat difficult to solve. It is, however, probable that in the majority of cases the pyrites was contemporaneous with the consolidation of the rock in which it occurs, although it is also possible that it may have occasionally owed its origin to the subsequent passage through the rock of metalliferous solutions. . . .

"Below the water-level, which usually very nearly coincides with the zone of decomposition, veins of a class which, on the whole, have proved very misleading to the miner, although often rich in gold, usually disappear. These follow the lines of jointing of the rock, and are probably due to the decomposition of auriferous pyrites and the re-deposition, from solution, of a portion of its material in local fissures. . . . Besides the veins above referred to, there are, associated with the intrusive auriferous rocks, others which Mr. Daintree considers as being of far greater practical importance, from being generally of greater width and more likely to be persistent in depth. *These he regards as the result of hydrothermal agencies which preceded and accompanied the protrusion,** and which in some cases continued long after the intrusive rock had cooled down."

Again, I quote the following:†

"Daintree, Hacket, Wilkinson and others have shown that a large portion of the gold in Victoria and Queensland is due to the agency of intrusive dikes of felstone, elvan and diorite, so that reefs of quartz in Silurian rocks are not, as was at one time supposed, the exclusive source of Australian gold.

"At Timbarra, gold is found in granite; these gold-fields consist of a granitic tableland, traversed by dikes of eurite‡ and pegmatite, also occasionally showing veins of auriferous quartz, *which may possibly be segregation deposits.*§ The weathered granite is sluiced, and very fine gold, to the extent at times of 5 dwt. to the ton, is obtained. *Gold has been found to occur here in unaltered granite, and in eurite,*‖ as well as in the decomposed granite."

In the Transvaal, in the Lydenburg district, a quartz-vein in a diorite dike was worked at Waterfall creek,¶ and at Ophir Hill is a silicified bed of dolomite, which has been—

* The italics are mine.—J. E. S.

† *Op. cit.*, p. 649.

‡ "Alaskite."—J. E. S.

§ The italics are mine.—J. E. S.

‖ The italics are mine.—J. E. S.

¶ Phillips and Louis, *op. cit.*, pp. 734–5.

"mineralized by gold-bearing solutions, which are in some way connected genetically with the numerous dioritic dikes that traverse the district." In the De Kaap district the rocks, "both stratified and granitic, are traversed by dikes of diorite and pegmatite. . . . In the neighborhood of the granite, these rocks occasionally carry small ferruginous intercalated deposits, which are generally auriferous. . . ."

3. *The Subordinate Connection of Gold-Quartz Veins with Basic Igneous Rocks.*

To avoid misunderstanding, I wish to say here that I recognize the fact that gold-quartz veins may occur in or near basic intrusives, and may, indeed, be genetically dependent on them. In the Kolar gold-field in India, for example, the auriferous veins invariably occur in a band of "greenstone trap."* In Western Australia the veins are reported to occur chiefly in diorite and diabase.† But certainly an overwhelming majority of gold-quartz veins occur in connection with rocks of the dioritic and granitic families,—that is to say, with the two most siliceous families of the three which make up most igneous rocks; and of these granite-diorite rocks, the veins show a decided preference for the more siliceous groups, such as quartz-diorite (tonalite), granite and alaskite. On the other hand, the intimate genetic connection of these typical gold-quartz veins with distinctly basic rocks, such as those of the diabasic family, may be safely called exceptional.

Therefore, the statement may be formulated that *although gold is present in all igneous rocks, and may be unequally distributed in any of them, yet the conditions for concentration by magmatic segregation become more favorable in proportion as the rock becomes more siliceous, and become most favorable in what has been shown to be the extreme siliceous product of rock-differentiation—in quartz-veins or dikes.*

The explanation of this is a problem for future study.

X. Résumé of the Evidence Concerning the Preference of Certain Metals to Accumulate, by Magmatic Segregation, in Certain Rock-Types of the Established Classification.

I have already pointed out that if the rarer elements, which have been disregarded in establishing the classification of igne-

* Phillips and Louis, *op. cit.*, p. 568. † Phillips and Louis, *op. cit.*, p. 700.

ous rocks, find themselves, as a result of magmatic segregation, more closely associated with certain of these rock-types than with others, it is not due to any merit in the classification, but because of the association of these elements with the commoner ones on which the classification is based. In proportion as this association is strong, the preference of a metal for a certain rock becomes more marked. These, then, are some of these preferences:

1. *Basic Rocks.*

Iron, as is well known, is most abundant in basic rocks, and iron-ore deposits formed directly by magmatic segregation are mostly confined to such rocks.

Chromium ore-deposits, due to magmatic segregation, are chiefly confined to the most basic rocks (peridotites) and their alteration products (chiefly serpentine).

Platinum.—Platinum also is characteristic of the most basic rocks (peridotites and serpentine).

Nickel is frequently closely associated, as the product of magmatic segregation, with iron, chromium and platinum, and is especially found in the most basic rocks.

Vanadium is chiefly found in basic rocks.*

Copper.—On account of its easy mobility, copper occurs in many different rocks, and as the result of many varied processes. Yet it seems to be especially connected with, and at home in, basic rocks. De Launay says:† "Copper is geologically close to nickel, with which it is frequently met, notably in the peridotites of Canada, for, like nickel, it is, above all, a metal of the basic rocks. . . ."

2. *Siliceous Rocks.*

Molybdenum is chiefly found in connection with the siliceous igneous rocks.

Tin is seldom met with except in connection with granite.

Tungsten has practically the same associations as tin.

The rarer elements in general seldom occur in notable amount, except in pegmatites and granitic rocks.‡

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* *Résumé* by J. F. Kemp, *Ore-Deposits of the United States and Canada*, 3d edition, p. 36.

† "Contribution à l'Étude des Gîtes Métallifères," *Annales des Mines*, August, 1897, 9th series, vol. xii., p. 191.

‡ Kemp, *Ore-Deposits of the United States and Canada*, 3d edition, p. 36.

Gold, as has just been argued, while a mobile metal and widely distributed, seems to show a preference for the siliceous igneous rocks.

XI. The Relation between Ore-Deposits Due to Magmatic Segregation and Other Ore-Deposits.

In nature there are no hard and fast lines. So we find that ore-deposits originating, as argued, by magmatic segregation, pass by transition stages into others whose characteristics demand a different interpretation.

Especially close is the connection between certain magmatic segregations, certain contact-deposits, and certain deposits of gaseous-aqueous (pneumato-hydatogenic) origin.

Magmatic segregations take place while the rock, as a whole, is yet liquid; they are due to the mobility of elements or crystallizing minerals in this liquid, and may be conveniently conceived as taking place through the action of convection-currents.

Upon the cooling of an igneous intrusive rock, however, what might be called a forced segregation takes place. As the rock becomes solid, those materials which are "left-over" are expelled, and find their way into the neighboring rock, or along the fissures of the igneous rock itself. These "left-over" materials consist chiefly of water, which is usually highly siliceous, and contains a great variety of other mineral matters in solution, and also, very commonly, an unusual quantity of gases. In these excretions the proportion of gaseous to liquid constituents appears to vary as widely as possible—dependent, probably, partly on the nature of the cooling rock, partly on the conditions or rate of cooling, etc. According as the gaseous or the liquid elements preponderate, there result ore-deposits (for these expelled solutions often contain metals), which, from the internal evidence they offer as to their mode of formation, may be classed as pneumatogenic (pneumatolytic), pneumato-hydatogenic (gaseo-aqueous), or hydatogenic. To the first class belong the ores deposited by volcanic fumaroles, and the writer has referred the gold-ores of Mercur, Utah, to the same general division.* The second and third classes are

* J. E. Spurr, "Economic Geology of the Mercur Mining District," *16th Ann. Rpt. U. S. Geol. Survey*, Part II., p. 452.

of great importance. To the second belong the tin-veins, and to the third the "contact-deposits" proper.*

The gold-quartz veins, such as have been considered to be formed by magmatic segregation, the veins of the tin-group, and the contact-deposits proper, are perfectly distinct in characteristics and origin; yet between the first and the second, and the second and the third, there are all transitions, indicating transitions in the conditions which produced them. In all three cases the mineralizing agents may be described as highly-heated water heavily charged with silica, and containing metals and other mineral matters, all being directly derived from an igneous rock in its last stages of consolidation from a molten condition. All are characteristic of the more siliceous intrusives. Tin-veins seem to be confined to granitic rocks; gold-quartz veins prefer granite, and after that diorite; while contact-deposits, like contact-metamorphism in general, are chiefly characteristic of the more siliceous rocks, granite or diorite. Yet the first may be conceived of as quietly segregating under pressure in a mobile though probably slowly congealing magma, the second as escaping from a cooling-rock into fissures or other channels, with relief of pressure and the consequent assumption of different form and proportion, and the third as also escaping from a cooling-rock, but under pressure and penetrating largely by capillary or osmotic action into the rock in contact with the igneous body. Each of these processes involves a different selection of elements by the solutions—hence tin-veins and gold-quartz veins are generally quite distinct.

Many pegmatites are closely related to tin-veins. They not infrequently contain cassiterite, and are characterized by fluor and boron compounds, indicating gaseo-aqueous origin. Such pegmatites, like the true tin-veins, are not likely to contain gold, and cannot be taken as an indication of probable gold-quartz veins. On the other hand, pegmatites containing slight evidence of pneumatolytic origin may be closely related to and associated with gold-quartz veins. In some pegmatites gold has been found. But the quartz-veins that pass into relatively

* J. H. L. Vogt, "Problems in the Geology of Ore-Deposits," *Trans.*, xxxi., pp. 139, 140. *Genesis of Ore-Deposits*, pp. 650, 651. Waldemar Lindgren, "Character and Genesis of Certain Contact-Deposits," *Trans.*, xxxi., p. 226. *Genesis of Ore-Deposits*, p. 716.

fine-grained, highly siliceous igneous rocks, with slight display of coarse-grained pegmatite, have probably been formed under the most favorable conditions for the segregation of gold in them, *i.e.*, comparative freedom from the pneumatolytic actions which are so unusually important in forming the *cassiterite* veins. Yet the occasional presence of tin and its close associate, tungsten, as well as tourmaline, fluorite, etc., in gold-quartz veins shows that one set of conditions may pass gradually into the other. The occasional presence of tourmaline, fluorite, wolframite, tin, etc., in zones of contact-metamorphosis and in contact ore-deposits, contrary to the usual occurrence, is an illustration of the same principle.*

XII. The Sequence of Volcanic Eruptions Considered in Connection with the Sequence of Metalliferous Veins.

It has already been described how, in a certain volcanic field, the rocks erupted or intruded at different periods are of quite different character, and how dissimilar rocks may be most closely associated. Extremely acid and extremely basic rocks are often almost or quite contemporaneously intruded or erupted in the same locality. From this, and from the observed sequences, rough laws of succession have been deduced. These differ somewhat, according to the district in which observations were made in each case; but they practically agree in indicating that magmas tend to segregate into more basic and more acid (more and less siliceous) portions. The writer, following Professor J. P. Iddings, believes that an initial rock of intermediate composition ordinarily passes, by magmatic segregation, into rocks which are progressively more acid and more basic, till extremely siliceous and extremely basic varieties are obtained. According to this, if the rocks were regularly intruded or erupted at stated intervals, we might expect to find the law of segregation fully illustrated in the succession of rocks. Sometimes, indeed, this is the case; but very often the eruptions have taken place irregularly, so that the normal succession is hardly recognizable.

Prof. J. F. Kemp has called attention to cases of successive

* Compare J. H. L. Vogt, "Problems in the Geology of Ore-Deposits," *Trans.*, xxxi., p. 139. *Genesis of Ore-Deposits*, p. 650.

vein-formations of quite different characteristics in a single district, and has supported the idea that new intrusions of igneous rock, of a character different from the preceding intrusions (rather than new fractures, as has often been assumed), are responsible for the differences, the metals extracted from one igneous rock being different from those derived from another.* With this idea the writer is in general accord, and would add the suggestion that also the difference in the veins at different periods may often depend upon the progress of rock-segregation (differentiation) in a still unconsolidated magma, from which the metals, directly or indirectly, are derived. By applying the idea of the change of segregated metals with the progress of general rock-segregation, some light on mineral association and succession may possibly be obtained. For example, in many districts of the world gold and platinum are closely associated in placers. In these districts it is usual to find extremely acid and extremely basic rocks (complementary varieties) intimately associated, representing apparently an extreme stage of rock-segregation; and frequently, as in the Urals, the platinum is found to be derived from the basic rocks (peridotites), and the gold chiefly from gold-quartz veins in the siliceous ones (granite). This is one of the simplest cases. In an earlier stage of the rock-segregation, when the extreme rock-types had not originated, we would not find any platinum-segregations, and the occurrence of gold-quartz veins would be less probable. A similar example of mineral association, probably dependent upon rock-segregation, is the occurrence in the gold-quartz district of Forty-Mile creek, Alaska, of an ore containing nickel, iron, chromium and magnesia, and no gold.† Just as the gold-quartz veins here are intimately associated with the ultra-siliceous dikes, so this ore is probably connected with the ultra-basic ones; and, as the two sets of dikes have been considered complementary and due to a single process of segregation, the contrasted ore-formations must be considered in the same light.

In many districts it has been noted that the veins of different

* "Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., p. 180. *Genesis of Ore-Deposits*, p. 691.

† J. E. Spurr, "Geology of the Yukon Gold-District," 18*th Ann. Rep. U. S. G. S.*, Part III., p. 295.

periods have different contents. Professor Kemp* has called attention to the San Juan region in Colorado, where the different veins have been classified by T. B. Comstock as follows: 1. The northwest system with tetrahedrite. 2. The east and west with bismuth, and less often nickel and molybdenum. 3. The northeast with tellurides and antimony, and sulphur-compounds of the precious metals.

The same writer cites, in this connection, the Telluride district in Colorado, where a heavy vein is cut out and faulted by a later one of different metalliferous character. He also recalls an occurrence near Freiberg, Saxony, where seven sets of veins have been recognized, distinct from one another mineralogically, and probably introduced at different periods. At Butte, Montana, there are two distinct sets of veins, one containing silver and no copper, and the other containing copper, silver and gold.

At Mercur, Utah, the writer has described two ore-bearing zones which are parallel and lie about 100 to 150 ft. from one another.† They are of different ages: the oldest, the "Silver Ledge," contains silver with only traces of gold, while the younger, the "Gold Ledge," contains gold to the exclusion of silver, together with cinnabar and realgar, minerals not found in the Silver Ledge.

This list might be amplified, but will serve to show the main features of the problem.

It is not safe or reasonable to refer such differences in veins to any one universal cause. In the Mercur case, the writer has reasoned that the Gold Ledge is essentially a pneumatogenic deposit, due to gases ascending along fissures; and that the Silver Ledge is a contact-deposit, due to waters *occluded* in cooling from the intrusive sheet of rhyolite porphyry at whose contact it occurs. In such cases the different nature of the mineralizing solutions is sufficient to produce entirely different combinations of vein-minerals derived from a single magma, although a change in this magma itself by segregation, or the

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* "Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., p 179. Also *Ore-Deposits of United States and Canada*, fourth edition, p. 288 *Genesis of Ore-Deposits*, p. 691.

† J. E. Spurr, "Economic Geology of the Mercur Mining District, Utah," 16*th Ann. Rep. U. S. Geol. Survey*, Part II., p. 403.

intrusion of a rock of a new kind is, of course, not improbable. In other cases the different character of rocks traversed by the same mineralizing solutions might operate to cause the precipitation in one rock of a different combination of minerals from that precipitated by another. Where, however, the different veins are in the same rock, and belong in the same category of ore-deposits (from the standpoint of the process of formation), the assumption of a change in the character of the igneous rock below, whether by new intrusions (mechanical change) or by segregation (chemical change), will probably be often justified. The fact that the different veins often occupy fractures of different trend and age is far from opposing this theory, for it is only by the aid of mechanical accidents like fracturing that new solutions can rise, and by their effects bear witness to the change that would otherwise not be known.

XIII. The Persistence of Petrographic Provinces, Considered in Connection with the Persistence of Metalliferous Provinces.

While an igneous rock of a certain kind is not necessarily limited to a certain part of the earth's surface, yet the rocks of a given district generally show marked and persistent differences, taken as a whole, from the rocks of other, even adjoining, regions. To these districts, showing within themselves, no matter how varied the rocks they contain, a certain "kinship" or "consanguinity" between the different rocks, the term *petrographic provinces* has been assigned.

For example, many of the rocks of northern Minnesota, especially the granites, show a constant excess of soda over potash, producing the variety soda-granite, which appears to be characteristic of this region.* Other regions have a large development of rocks especially high in the alkalies,—phonolites, nepheline-syenites, etc., rocks which in most regions are wanting. Rocks characterized by an especially great proportion of magnesia, such as peridotites, occur in certain regions and are wanting in others.

The differences which give rise to these petrographical provinces are evidently due to the unequal distribution of the com-

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* 21st *Ann. Rep. Minn., Geol. and Nat. Hist. Survey,* pp. 41, 42.

moner rock-forming elements, upon which rock-classification is based, in different portions of the earth's crust. In one region sodium is especially abundant, in another both sodium and potassium, in another magnesium, in another aluminum, etc. Some petrographic provinces show mineralogical differences which are wonderfully slight, considering their persistence—in one the granites may be chiefly hornblende granites, for example, and in another almost entirely biotite granites, owing to constant, slight differences in the proportions of aluminum, magnesium, calcium, potassium, etc., present in each. The existence of these petrographic provinces, characterized by different proportions of the commoner rock-forming elements, has been explained by extending the theory of rock-segregation or differentiation so as to make it applicable on a large scale, and by supposing that in great internal reservoirs (presumably connecting, or at least once connected) certain elements, by reason of their affinity, become more or less concentrated in certain portions. We are quite in the dark as to what might be a possible cause for this (as yet) hypothetical process, for certainly the theory of concentration by convection-currents on cooling has slight application here; but in science the apprehension of the fact very commonly runs ahead of the explanation, and this idea is at least a good working hypothesis, which has much to recommend it. By this theory all igneous rocks (in so far as they are not formed by fusion of sedimentary rocks or by mixing of already different magmas) have originated chiefly by segregation from an original universal magma.*

If one accepts as a working hypothesis (as the writer has done) this theory that the unequal distribution or the relative concentration of the commoner rock-forming elements in certain parts of the earth's crust (giving rise to distinct petrographic provinces and rock-types) has been effected by magmatic segregation, one cannot avoid accepting the same theory for the less common rock-forming elements.

If one accepts this for the distribution of sodium, potassium, aluminum, magnesium, titanium and phosphorus, he must accept it for manganese, barium, chromium, nickel, strontium, lithium, chlorine and fluorine; and if he applies it to these

* J. P. Iddings, "The Origin of Igneous Rocks," *Bull. Philosoph. Soc. Wash.*, vol. xii., p. 185.

latter, he must extend it to tin, bromine and cobalt; to lead, zinc, copper, arsenic, antimony, wolfram; to mercury, silver, bismuth, vanadium, tellurium and thorium; to gold and platinum, and even to iridium, ytterbium and germanium.*

Following this idea, and observing that some regions are especially rich in sodium, some in magnesium, and some in titanium (petrographic provinces), we should expect to find some especially rich in chromium, some in nickel, some in tin, some in lead, some in copper, some in mercury, some in gold, some in platinum, etc. This is well known to be the case, and these regions, characterized by special combinations or amounts of the rarer, especially the commercially-valuable, metals, I desire to call *metalliferous provinces.*

A metalliferous province does not necessarily coincide with a petrographic province, for the reason that I have already pointed out—namely, that the petrographic province and its contained rocks is classified solely on the basis of the commoner rock-forming elements; while the rarer ones, upon the distribution of certain of which *metalliferous provinces* may be distinguished, follow independent laws of segregation, which, nevertheless, may sometimes partly coincide with the laws of segregation of some of the commoner elements, by virtue of an affinity or preferential association between a rare element and a common one.

The helpfulness (to the investigator) and yet the final unreliability of these affinities will be at once seen upon consideration. Platinum, for example, is undeniably most abundant in basic rocks—peridotites; that is to say, it prefers the company of elements like magnesium, calcium or iron, and objects to that of silicon; yet all peridotites do not contain platinum, at least in equal amount. It is only in certain metalliferous provinces that platinum is sufficiently abundant in peridotites to become commercially interesting. The same remarks apply to chromium, nickel, etc. On the other hand, tin seems to prefer the society of silicon, and is always found in close connection with siliceous igneous rocks, chiefly granites; yet not all granites contain tin in notable quantities. The variation is

* For the relative proportion of the elements in the earth's crust, see F. W. Clarke, *Bull. U. S. G. S.*, Nos. 78 and 148; also J. H. L. Vogt, "Ueber die relative Verbreitung der Elemente," *Zeitsch. für praktische Geol.*, 1898, p. 225.

enormous. So a study of the distribution of granite gives only a slight clue to the distribution of tin, and a knowledge of the occurrences of peridotite is only the first step toward a knowledge of the occurrences of chrome or nickel deposits. This principle is of wide application. Igneous rocks have long been recognized as the ultimate sources of many, if not most, ore-deposits. Yet not all igneous rocks are connected with ore-deposits. One mass of diorite, for example, may be connected with rich ore-bodies (formed, it is needless to say, in most cases, finally through the concentrating action of circulating waters), while an exactly similar diorite in another region may have no ores at all associated with it. One may explain this by assuming that in the first-mentioned case there have been abundant circulating waters, especially heated ones, and plentiful faults, fractures and zones of weakness permitting the passage of these mineralizing agents; and that in the second case these conditions for concentrating the disseminated metals have not been so favorable. The writer recognizes these considerations as of vast and universal importance; and yet a comparison of regions equally favored with igneous intrusives, with abundant circulating waters, with the necessary channels for circulation and permeation, and with rocks favorable for the precipitation of the metals held in solution in the circulating waters (such as limestones, carbonaceous shales and porous sandstones), may show an utter difference in the amount and nature of the minerals concentrated. Moreover, the same type of rock—a diorite, for example—may be associated with chiefly silver-ores in one region, with copper in a second, and with gold in a third.

Detailed investigations concerning the less abundant metals in igneous rocks, although they have rendered the science of ore-deposits the inestimable service of proving the presence of these rarer elements, afford little ground for more extended conclusions, on account of their being so few and (necessarily, from the minute quantities dealt with) so inaccurate.

Yet it seems that they also corroborate the conclusion that the metals are very unevenly distributed.

Professor J. F. Kemp remarks:*

* "The Rôle of the Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., p. 172; also, *Genesis of Ore-Deposits*, p. 684.

"Nevertheless, it is a fact of the greatest importance that the presence of the metals* in the igneous rocks has been established. Not all igneous rocks have yielded such results on assay. The general experience has been that when samples of several varieties have been collected in a given district, some have proved barren; and it must be admitted that some negative results have been obtained. As a rule, however, they are decidedly fewer than the positive results. It is likewise true that not all igneous districts contain veins of ore."

To this quotation the writer adds the suggestion that most of the assays made have been of igneous rocks in metalliferous districts, where we should *a priori* (according to the ideas previously set forth) expect a greater proportion of the metals; and that, if assays of rocks in non-metalliferous districts were made, the proportion of negative results might be decidedly in excess—although then, as now, the term "negative results" would probably only mean that the metals sought for were in quantities too small to be detected by chemical methods.

The chemical determinations of the presence of the more abundant of the relatively rare metals give results fully confirming the conclusions reached as to their unequal distribution in similar rocks. Nickel, for example, is recognized as especially at home in the most basic rocks—peridotites and pyroxenites; but Vogt† gives a table of nickel determinations in 32 rocks of this kind, which vary all the way from a trace to 0.6 per cent.

Petrographic provinces may be relatively small in extent, or they may be enormous. The writer has made a study of the volcanic region of the Great Basin,‡ where an area whose limits are not determined, but which extends as far east as Salt Lake, west into the Sierra Nevada, north into Idaho and Oregon, and south into California, shows the same types and the same general succession of Tertiary lavas. From later studies by the writer in the Monte Cristo mining district, Washington, it appears that the Tertiary eruptions here also correspond in types, age and general succession to those of Nevada;§ similar rocks, age and succession have been ob-

* Referring, of course, to the least abundant metals.—J. E. S.

† "Relative Verbreitung der Elemente," *Zeitsch. für prakt. Geol.*, July, 1898, p. 236.

‡ *Journal of Geol.*, vol. viii., p. 621.

§ See article by author on "The Ore-Deposits of Monte Cristo, Washington," 22*d Ann. Rept. U. S. Geol. Survey,* Part II., pp. 711–865.

served on the Southern California coast;* and as far away as Mexico the studies of Ordoñez† have established the fact that the principal rocks, their succession and age, remain the same. Without being in danger of carrying this correlation to excess, I may point out that the Pliocene olivine-basalts of the Sierra Nevada‡ are abundantly present in Oregon and Washington; that the British Columbia basalts are approximately, at least, of the same period;§ and that throughout the whole of Alaska and into the Behring Sea occur olivine-basalts of Pliocene age.||

Again, the abundance of basic andesites (typically augitic, often hypersthene-bearing, and verging towards basalts), all belonging to one epoch (very late Pliocene-Pleistocene), in a continuous belt in Alaska, running the whole length of the Aleutian Islands and peninsula, turning the same angle as the chief orographic and topographic features, and running down the coast past Sitka;¶ the occurrence of the same rocks, belonging to the same age, in Washington and Oregon (Mt. Rainier, etc.); the extension of the belt through the Sierra Nevada and along the western part of the Great Basin; finally its extension into Mexico,**—this is all striking, and deserves recognition. Moreover, this belt of late Pliocene-Pleistocene augite (hypersthene) andesites extends through Central and South America, in the Andes.†† In Alaska and in the Andes some of the cones of this epoch are still active; but the majority have become extinct.

It appears, then, that the whole extreme western part of the western hemisphere (the Pacific coast of the Americas) is a zone occupied by what (at some periods, at least) is and has been a single petrographic province.

It remains to be seen whether this province is not continued

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* I regret I have not at hand the paper of Mr. Smith in a recent U. S. Geol. Survey Ann. Report, in order to give an exact reference. (Santa Catalina Island.)

† "Las Rhyolitas de Mexico," *Boletin del Instituto Geologico de Mexico*, No. 14.

‡ J. E. Spurr, *Jour. Geol.*, vol. viii., No. 7, chart, p. 643.

§ G. M. Dawson, *Ann. Rep. Geol. Nat. Hist. Surv. Canada*, vol. iii., Part I., p. 37 B.; also, *Trans. Royal Soc. Canada*, vol. viii., Sec. 4, p. 15.

|| J. E. Spurr, "Geology of the Yukon Gold-District," *18th Ann. Rep. U. S. Geol. Surv.*, Part III., p. 250.

¶ J. E. Spurr, "Reconnaissance in Southwestern Alaska," *20th Ann. Rep. U. S. Geol. Surv.*, Part VII., Map 13.

** Ezequiel Ordoñez, *op. cit.*, p. 66.

†† Zirkel, *Lehrbuch der Petrographie*, 2d Edition, Vol. ii., pp. 831–2.

into Asia with the change of orogenic trends in Alaska from northwest to southwest. The line of late Tertiary-Pleistocene volcanoes, which extends along the Aleutian Islands to Kamchatka, is represented by 15 or 20 cones in this peninsula; this line, following the general orogenic trend, runs southwest through the Kurile Islands, the islands of Japan, and the Philippines, into the East Indies. Andesites—largely pyroxene andesites, and frequently hypersthene andesites—are characteristic of this chain also, as far as the famous volcano of Krakatua. This investigation might profitably be carried still further, but this is hardly the place for it.

Turning from these examples of petrographic provinces on enormous scales, we find that metalliferous provinces may also be of light extent, or may be exceedingly large. Taken broadly, they often coincide more or less roughly with petrographic provinces, just as these are apt to show some correspondence in their position and trends with zones of folding and fracture in the crust, with mountain ranges and the borders of continents. A metalliferous province which I have been studying somewhat lately is the rich chrome-bearing province of Turkey, which, with its center at the western coast of Asia Minor, extends across the Ægean Sea and includes Macedonia and Eastern Greece, and in the other direction stretches over the western and southern portions of Asia Minor. This metalliferous province is connected with a petrographic province marked by ultra-basic igneous rocks and serpentines, with which the ore is associated; yet similar rocks are found in other regions, without the corresponding abundance of chrome.

Taking a larger example, compare, in North America, the Appalachian with the Cordilleran region. That there is a certain kinship among the ores of the Appalachian chain and its allied ranges has long been recognized by mining men. *It is recognized that the metals, though present, are constantly far less abundant than in the Cordilleran region.* Every now and then one hears of veins found in this region which give rich results on assay; but the discovery, though heralded in the newspapers, makes no disturbance in the mining world, for the mining man knows, from long experience with such discoveries, that the vein will directly "peter out." Gold-bearing veins

are pretty thoroughly scattered along this zone from Nova Scotia to Georgia; but the uncertainty and the relative poverty of these gold-deposits is proverbial.

Taking the western Cordilleras, on the other hand, we may remember that the California miners followed new finds northwestward, along the trends of the mountain ranges, into the Frazer river country, the Caribou district, the Omenica, the Cassiar, the Pelly, and the Yukon, until the slow progress has brought them to the neighborhood of the Behring Straits (the Nome district). It seems exceedingly probable, also, that this true "mineral zone" extends into Siberia. For I do not hesitate to call it a mineral zone, although the gold-quartz veins of the Yukon are far different in age from those of California. In fact, the existence of rich gold-ores along this zone, in deposits of various ages, and made under various conditions and in various rocks, only serves to emphasize the conclusion that this zone is essentially a metalliferous province, marked by a greater proportion of gold (considering the question of the gold alone) than the earth's crust in general.

Concerning metalliferous sub-provinces within the Cordilleras, I quote the following from Phillips and Louis,* not having access to the original authorities:

"Mr. R. W. Raymond,† in a paper on the mining districts of the United States, recalls the fact that W. P. Blake, in a note to his *Catalogue of California Minerals*, first pointed out that the mining districts of the Pacific slope are arranged in parallel zones, following the prevailing direction of the mountain ranges. More recently, Clarence King has summarized these phenomena nearly as follows: The Pacific coast ranges carry, on the west, quicksilver, tin and chrome iron-ores. The next belt is that of the Sierra Nevada and of the Cascade mountains of Oregon, which, upon their western slope, carry two distinct zones, a foot-hill chain of copper-mines, and a middle line of gold-deposits, which extend into Alaska. Lying to the east of this zone, along the eastern base of the Sierras, and stretching southward into Mexico, is a chain of silver-mines which are frequently included in volcanic rocks. Through Central Mexico, Arizona, Central Nevada and Middle Idaho there is another line of silver-mines which more often occur in the older rocks. Through New Mexico, Utah and Western Montana lies another zone of argentiferous galena lodes; and again, to the east, the New Mexico, Colorado, Wyoming and Montana gold-belt forms a well-defined and continuous chain of deposits. Raymond agrees that this parallelism exists, though in a somewhat irregular way, and that it is chiefly referable, as Blake and King have shown, to the structural features of the country."

This quotation the writer makes without deciding his belief

* *Ore-Deposits*, 2d ed., p. 740.

† *Trans.*, i., p. 33 (1873).

for or against the divisions as claimed. Undoubtedly the later discoveries within this region have been so varied as to make some of the distinctions doubtful; yet a careful consideration of the Cordilleran ore-deposits of western North America would probably result in the determination of definite metalliferous sub-provinces, which might or might not coincide with those specified. That Nevada, in general, is part of such a sub-province, characterized especially by the abundance of silver, with other minerals subordinate, is strikingly illustrated by the fact that the vigorous mining industry of this State, so exceedingly rich in ore-deposits, was permanently prostrated by the decline in the price of silver, while other regions, differing from this in the nature of their metallic wealth, have prospered.

XIV. Conclusion.

Our inquiries lead us to the hypothesis *that by magmatic segregation the metals of commercial value, as well as the other rock-forming elements, are irregularly and to a certain extent independently concentrated in certain portions of the earth's crust. Such portions, characterized by the relative abundance of certain metals, may be called metalliferous provinces.* It is in these provinces that ore-bodies will generally occur. The provinces may or may not be closely identified with petrographic provinces (divisions based on the relative abundance of the commoner metals and other elements), although, by reason of the chemical affinity which exists between certain of the rarer metals and certain of the commoner elements, they probably generally do so, to a certain extent at least. *Moreover, within these metalliferous provinces (as is the case within the petrographic provinces) magmatic segregation produces sub-provinces, secondary, perhaps, in theoretical importance to the grander divisions, but of more practical interest to miners.* To limit, again, the scope of our views, *by magmatic segregation the rarer metals (like the commoner elements, again) are in many cases preferentially concentrated into certain rocks in a given sub-province.* Finally, *within these rocks the metals may be segregated chiefly into certain portions, even producing, in the case of the commoner metals (iron, chrome, nickel, etc.), workable ore-deposits without further concentration; and, in the case of the less common ones, either directly producing workable deposits (certain gold-quartz veins, certain tin-veins, possibly certain platinum segregations—Urals—)*

or producing rocks relatively so rich that it requires only the concentrating action of other agents (chiefly circulating waters) to create "ore-bodies." It is the writer's belief that *the origin of metal-producing districts, as contrasted with barren districts, is in most cases due primarily to magmatic segregation, and that an important class of ore-deposits is due directly to this.*

Added to this initial process, there are the varied effects produced by gases and liquids occluded by cooling igneous rocks, and the enormous work of waters, surface and underground, which, by continued solution and deposition as well as by mechanical concentration, may, under favorable conditions, operate to bring the disseminated metals within smaller and smaller compass. Underground, these waters may be hot or cold; they may be ascending, descending, or moving laterally; they may transport their metallic load only a fraction of an inch, a few rods, or miles. Their final effect is to create *directly* what is, perhaps, the most important type of ore-deposits. The study of ore-deposits is a study in concentration—the concentration of some of the finely-disseminated rarer rock-forming elements into more or less compact masses. This concentration is effected chiefly by these processes: (1) magmatic concentration; (2) concentration by occluded gases and liquids from consolidating magmas; (3) concentration by the action of hot-spring waters (generally ascending); (4) concentration by the action of cold surface-waters penetrating underground (generally descending); and (5) concentration by the effects (chiefly mechanical, though largely chemical) of surface-waters at the surface.

Any one of these processes may be chiefly responsible for a given ore-body, but in many cases two, three or more of them may be important. Moreover, the history of an ore-deposit may comprise cycles, or repetitions of the same processes at different intervals, before the final concentration is sufficiently complete. Take, for example, the Nome beach-sands, where the gold is concentrated from the concentrates of older beach-sands, now transformed into land by a crustal uplift.*

On Napoleon creek, a branch of Forty-Mile creek, Alaska, there was found a strip of rich stream gold-placer ground in

* Schrader and Brooks, *Trans.*, xxx., p. 242.

a district where working was not otherwise profitable. The gold was apparently derived from a conglomerate of probable Cretaceous age which formed a belt crossing the stream at this point. The composition of the conglomerate showed that it was derived from the rocks and quartz-veins of the ancient (Algonkian ?) gold-bearing series. In this ancient series, as already explained, the gold is believed to have been concentrated by magmatic segregation. Here, therefore, we have three distinct processes of concentration: (1) magmatic segregation (Algonkian ?); (2) mechanical concentration by surface-waters (beach-sands—Cretaceous ?); (3) mechanical concentration by surface-waters (stream-placers—Pleistocene). And it was only after the third process that the metal was sufficiently concentrated to become workable with profit—to become an ore-deposit, properly speaking.

POSTSCRIPT.

Since the above was written, the writer has received the interesting paper of Mr. Luther Wagoner on "The Detection and Estimation of Small Quantities of Gold and Silver."* Mr. Wagoner gives a series of delicate assays of California rocks, remote from mineral deposits, for gold and silver.

Four specimens of granite gave respectively the following weights in milligrams per ton: Gold, 104, 137, 115, 1130; silver, 7660, 1220, 940, 5590. One specimen of syenite showed gold, 720; silver, 15,430. A sample of diabase contained gold, 76; silver, 7440; and one of basalt, gold, 26, silver, 547. The sedimentary rocks tested were three specimens of sandstone from different localities, and two of marble (one of the latter from Italy). The sandstones gave respectively, in gold, 39, 24 and 21; in silver, 540, 450 and 320. The California marble showed gold, 5; silver, 212; the Italian sample, gold, 8.63; silver, 201. Several assays of San Francisco *bay-mud* (containing some organic material) gave gold from 45 to 125. Two assays of sea-water gave a mean of gold, 11.1; silver, 169.5.

These results are suggestive; and, although too few to base final conclusions on, the writer would like to call attention to some striking facts. On reckoning up the means of the results, we find that the granite averaged 371.5 gold and 3852.5

* *Trans.*, xxxi., p. 798.

silver; the sandstone, 28 gold and $436\frac{2}{3}$ silver; the marble, 6.8 gold and 206.5 silver; and the bay-mud, 85 gold.

The relative proportion of the precious metals in the sedimentary and in the igneous rocks first claims attention. The mean of all the igneous rocks assayed in gold $329\frac{5}{7}$, and silver $5546\frac{5}{7}$; of the sedimentary rocks (sandstones and marbles, not the bay-mud), 17.5 gold and 344.4 silver. That is to say, the mean of the igneous rocks assayed shows about 19 times as much gold and 16 times as much silver as the mean of the sedimentary rocks.

The relative proportion of the metals in the different sedimentary rocks is another point. The sandstones average 4 times as much gold and over twice as much silver as the marbles; while bay-mud (which on hardening would become shale) contains nearly 13 times as much gold as the marbles.

Take, next, the relative proportion of the metals in the different igneous rocks. We have in the list siliceous or acid rocks (granite and syenite) and basic rocks (diabase and basalt).

Diabase and basalt are, generally speaking, chemical and mineralogical equivalents, differing in their texture and structure. If we compare the average of the granites with that of the diabase-basalt, we find that the former is $371\frac{1}{2}$ gold and $3852\frac{1}{2}$ silver, while the latter is gold 51 and silver $4008\frac{1}{2}$; that is, the granites contain nearly $7\frac{1}{2}$ times as much gold as the diabase-basalt, but only about the same quantity of silver. If we add the syenite assay (probably unusually high) to those of the granites, and again compare the result with the diabase-basalt contents, we find that the acid rocks contain 9 times as much gold and $1\frac{1}{2}$ times as much silver as the basic ones.

In spite of the small quantity of data, these results are in accordance with the theoretical conclusions arrived at in this paper. One of these conclusions was concerning the higher content of precious metals in the igneous rocks as compared with the sedimentaries. A second conclusion was in regard to the relative concentration of the metals in the different sedimentaries—least in the limestones, which are *calcium* concentrations effected largely chemically from the sea-water through organic agencies; more abundant in the sandstones, which are *silica* concentrations, but effected mechanically and containing much *débris* from all sorts of rocks; and most

abundant in the bay-mud, which is a fine ground-up mixture of all rocks, and contains, besides, organic matter which is known to be a precipitant of metals from solution. A continuance of these experiments is highly desirable, to fix the point as to whether the order of richness in gold and silver of the sedimentary rocks is really 1, shales; 2, sandstones; 3, limestones.

Thirdly, as regards the igneous rocks, the uniformly superior gold content of the siliceous or acid rocks, as compared with the basic rocks, is noticeable. One must remark, also, that the same does not hold good for silver; for, although the basalt contains the least and the syenite the most, yet the diabase has a large amount. This, as far as it goes, is in accordance with the theory above advocated, that during the process of magmatic segregation the gold (*not* the silver) seeks the siliceous rocks by preference.

Principles Controlling the Geologic Deposition of the Hydrocarbons.*

BY GEORGE I. ADAMS, WASHINGTON, D. C.

(New York and Philadelphia Meeting, February and May, 1902.)

THERE is an extensive literature relative to gas, oil, and the more solid hydrocarbons; but when it has all been digested and summarized, the resulting information is far from being satisfactory. The problems which have received the most attention are naturally those which relate to the successful exploitation and utilization of the deposits. From what is known of their geologic occurrence, theories have been formulated and rules laid down for the guidance of prospectors. The technology of the products has been made the subject of special chemical investigations. The geologic interrelation of the hydrocarbons, however, has not been considered in a broad manner, and the principles which have governed the origin of the economic bodies have been but imperfectly expressed.

On the other hand, metalliferous deposits have been widely

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studied, and the broader principles of ore-deposition are formulated. The paper by Van Hise,* on "Some Principles Controlling the Deposition of Ores," in which the origin of the larger part of the ore-bodies is ascribed to the work of underground water, may be cited as a comprehensive explanation of the most important class of metalliferous deposits. A similar explanation of the origin of the hydrocarbons must ultimately be formulated.

It is not purposed here to attempt the formulation of such a theory. The facts are altogether too few or too imperfectly known to admit of it. If, however, we follow the lines of reasoning suggested by the principles controlling ore-deposits we shall be led to fruitful inquiry, and experimentation will be suggested which should ultimately be taken up.

Accepting the organic origin of the natural hydrocarbons, we may divide all noteworthy deposits of such materials in the earth's crust into:

(1) Those resulting from sedimentation.

(2) Those accumulated through underground circulation.

As accumulated bodies, resulting from sedimentation, may be mentioned coals, lignites and fossil gums. The disseminated hydrocarbons of this class are found in carbonaceous shales, pyroschists, bituminous limestones and other sedimentary rocks with which they were deposited, and from which they have not been transferred; they include shale gas, marsh gas, and the small quantities of solid and fluid hydrocarbons which are of little economic importance.

The hydrocarbons which have accumulated through underground circulation are natural gas and petroleum in reservoirs, and maltha and asphalt in fissures and openings. The disseminated occurrences of this class are the hydrocarbons found impregnating sedimentary and occasionally igneous and metamorphic rocks, which originally held no such material. They are in solid, liquid or gaseous form.

It is appropriate to mention here the forms of carbon,—natural coke, graphite and diamond,—which are chemically the simplest products of the same general processes which produce the complex hydrocarbons, and which, like them, may have organic matter as their original source.

* *Trans.*, xxxi., p. 284, and *Genesis of Ore-Deposits*, 282.

This discussion deals more particularly with those deposits of hydrocarbons which have resulted from underground circulation. As it is proposed to emphasize the fact of circulation, those substances which are more readily transferable will be especially considered. These are natural gas and petroleum, or, as they are more commonly termed, gas and oil. The physico-chemical relations of gas and oil to the other hydrocarbons should not be forgotten, and it is not intended here to consider them as separate classes of deposits, as has been too commonly done.

The following brief statements are given as a summary of the points upon which writers are quite generally agreed:

1. The source of gas and oil is the organic matter which was deposited in the sedimentary formations.

2. The manner in which they are formed is perhaps only vaguely understood, but is commonly stated to be a process of decomposition and distillation.

For their existence in economic quantities the following conditions are essential:

1. A formation which, because of its more or less porous nature, will serve as a conductor and reservoir, and which is favorably located with respect to the source of supply.

2. Structure which is favorable to their accumulation.

3. An impervious cover which will hold them in.

The reservoirs are rocks, such as sandstones and limestones, which have fracture-spaces or open texture. The cover is commonly a shale. A favorable structure is an anticline or upward arching of the formation. Arrested anticlines and terraces are the less symmetrical forms of this structure.

Accumulation within the reservoir proceeds in accordance with hydrostatic laws, and the oil and gas arrange themselves in the openings in the rocks in accordance with their specific gravities. Since oil and gas are lighter than water, when they are present in a permeable stratum, the oil and gas will be displaced upward.

There are two causes of the pressure of oil and gas in the rocks: the hydrostatic force exerted upon them by circulating water, and the expansive power of the gas present.

While the above summary may appear to be an adequate statement of facts, a knowledge of which is essential to the

exploitation of the deposits, it is far from being a satisfactory explanation of the origin of the deposits. On the chemical side it has been demonstrated that the hydrocarbons are derivable from organic matter. The chemical changes which they may undergo within the earth have, however, not been carefully studied. The more general physical laws have been accepted as controlling their accumulation, but the processes have been neglected. There are, moreover, physico-chemical problems which are more elusive and difficult.

From the principles which are considered as controlling the deposition of ores, certain corollaries may be drawn which are applicable to the hydrocarbons. They are as follows:

1. Oil and gas and the related hydrocarbons are derived from matter originally deposited by the processes of sedimentation within the sedimentary rocks.

2. Their concentration as economic deposits is the result of circulation.

3. In their movements they have been influenced chiefly by gravity.

4. Other factors which influence their movement are temperature and pressure.

5. Their movements have been through capillary and supercapillary openings, but principally through capillary openings.

6. During their movement through the rocks they have been in intimate relation with underground water.

7. Water, in its circulation, issues at a lower level than its intake. The tendency of oil and gas is apparently to issue at a higher level than its source of origin.

In explaining the origin of ore-deposits it has been shown that the metals are carried in solution by underground water. The solubility or miscibility of the hydrocarbons in water has not been a subject of special research. If the sedimentary rocks were deprived of their water contents, the gaseous hydrocarbons would readily escape to the surface unless held by the structure of the rocks. The liquid hydrocarbons would follow a path similar to that which water does. Water, however, may be considered as always present. Very little is known concerning the relation of the hydrocarbons to water within the earth's crust. In the case of the transfer of the metals they are in solution in the circulating water; in the

case of the transfer of the hydrocarbons, the relation is one of mechanical mixture and, to some extent, solution. Oil and water are commonly regarded as not miscible; but there is reason to believe that, with the varying conditions of temperature and pressure, solution of certain of the hydrocarbons takes place; and, if it occurs only to a limited extent, it is a potent factor in their transfer. Where the relation is one of mechanical mixture (or where, as in accordance with the popular notion, the hydrocarbons float upon or are suspended in the water), the movement of the hydrocarbons, where water is descending, would be in the reverse direction from that of water. If solution takes place, or if the hydrocarbons are in any degree miscible, their movement will be with the water.

The deposits of hydrocarbons which are found within the same geologic horizon vary in composition with the locality. It is not improbable that they may have been derived from the same broadly disseminated organic matter. In accounting for the difference in their composition, we may appeal to the vicissitudes which they have undergone since their formation. The heavier and lighter hydrocarbons are readily separable in the laboratory. It remains for us to discover what processes effect this separation within the earth. Factors which may there be appealed to are differences of temperature and pressure, which will effect the solution of the hydrocarbons in water and of heavier hydrocarbons in the lighter ones.

As helpful to an understanding of the origin of deposits of oil and gas, we may discuss the geologic conditions which maintain in the Cretaceous formations outcropping in the foothills of the Rocky mountains in Colorado, and, extending eastward under the Plains region, are found again outcropping in central Kansas. The shales contain notable amounts of disseminated hydrocarbons wherever they have been seen in outcrops or have been reached by deep borings. Economic deposits of oil and gas, however, have thus far been found only at a few localities;—for example, the recently-discovered field at Boulder, Colorado. In the series of Cretaceous rocks is the porous Dakota sandstone, which is a well-known water-bearing horizon, and which has been extensively studied, since it is a source of artesian flows. It is generally stated that the water enters this formation at the foothills and finds issuance in the

Plains region. The circulation of underground water, which takes place to a much more limited extent within the less porous formations which contain hydrocarbons, obeys the same general law. Accepting, now, the statement that the hydrocarbons are not miscible or soluble in water, the effect of the movement of underground water under hydrostatic pressure would be to cause the oil and gas to be displaced upward, *i.e.*, to ascend along the strata, toward the foothills. They would eventually find issuance, unless held at some intermediate point where the structure is such as to arrest their progress. If, on the other hand, the hydrocarbons are in any degree miscible with water, or are soluble in it, we should expect that the movement of the water from the foothills to the plains would carry certain of the hydrocarbons with it; also, that they would find issuance with the water through springs and fissures, or be accumulated at intermediate points.

As a third possible condition, certain of the hydrocarbons may be displaced upward against the flow of water, while others may be carried with it. Under these circumstances the conditions of circulation would result in the separation of the various hydrocarbons into distinct reservoirs, and subsequently, with changed conditions, the transfer of certain of the hydrocarbons from the reservoirs in which they had accumulated. As an example of the last condition, we may suppose a reservoir of hydrocarbons accumulated under an anticline through gravitative movement. If, for any reason, the temperature or pressure is changed, the power of water to dissolve certain fractions might be increased. The long-continued movement of water and hydrocarbons in contact would thus result in the transfer of these fractions, and the composition of the contents of the reservoir would be accordingly changed.

I desire here to call attention to a form of underground reservoir such as is found to contain oil and gas in some fields. This form of reservoir has not been sufficiently described or sufficiently emphasized, although it has been recognized by some writers. Usually, anticlinal structure is considered essential to the formation of a reservoir. The upper marginal portion of a sealed-in porous stratum, however, answers all the requirements for holding the hydrocarbons. If the bed is inclined, the hydrocarbons will gravitate upward. In case the bed is

discontinuous before reaching the surface, or changes in character so that it is not porous, the oil and gas will be held as efficiently as under an anticline, provided that the adjacent strata are impervious. Reservoirs of this type apparently occur in the Kansas-Indian Territory field, and at Corsicana, Texas.

Asphalt bodies occurring in fissures are a class of deposits quite distinct from the hydrocarbons found within the rocks. They are considered as being derived from the more liquid hydrocarbons through oxidation and the loss of the volatile fractions. I desire to speak of them here in order to call attention to certain conditions which obtain in their accumulation. Fissures are the result of the fracturing of a rock-mass, but they may widen and be extended gradually. It seems to me more reasonable, in most instances, to suppose that the asphalt may have accumulated gradually, and with the development of a fissure. The hydrocarbons, in a stratum which supplies the material to fill a fissure, follow the laws controlling circulation through rocks until they find issuance into the fissure. On entering the fissure the material is in a semi-fluid form, and in the presence of water will rise in the fissure. If water were not present, it would not rise above the level of the supplying stratum, since there would be no hydrostatic force actuating its flow. The process of solidification is probably slow, and may or may not keep pace with the supply. Obviously, the process of oxidation may vary with the conditions of filling of the fissure and with the circulation of water in the rocks adjacent to the mass. Where the asphaltic material is not brought into the presence of atmospheric oxygen, oxidation is effected through the agency of the ground-water. The loss of the lighter hydrocarbons from the mass must take place by transfer through water. Here pressure and temperature are important factors. Accordingly, we may appeal to the same causes in accounting for the differences in composition of the asphalt as in the case of the petroleums. After solidification of the asphalt has occurred in a fissure, it may be subjected to stress like any rock. The adjustment of stresses and strains is evidenced in the structure of the asphalt veins. Such accommodation may possibly be attended with changes in composition.

There is a popular notion that asphalt in veins is the result

of intrusion, *i.e.*, that it has been forced into fissures in some such manner as igneous intrusions are formed. This idea, however, cannot be supported, since the material, before it finds issuance into the fissures, exists within the pores and cavities of the rocks, and is not subject to stresses other than the hydrostatic pressure acting upon it. Stress in the rocks which would be capable of expelling the hydrocarbons from the pores or cavities would necessarily be great enough to deform the rock, and such a force cannot be appealed to in the fields where asphalt deposits occur.

In conclusion, I desire to call attention to the fact that in filtering oils through fuller's earth, the separation of the lighter oil from the heavier is obtained in a manner somewhat similar to that accomplished by fractional distillation. It is possible that in the underground circulation of the hydrocarbons the structure of the rocks through which they pass may be an important cause of variation in composition. Attention has been called to this fact by Dr. David T. Day in a paper read by him before the First International Petroleum Congress in Paris.

Amarillium.

BY WILLIAM M. COURTIS, DETROIT, MICHIGAN.

(New Haven Meeting, October, 1902.)

WHILE assaying some copper carbonate ore from the Frazer claims, Similakameen, B. C., I noticed that on parting the gold button a deep orange solution was formed. The button gave off pink bands in the nitric acid, which became deep orange at a short distance from it; and as it traveled over the surface of the porcelain dish, it left a deep orange track behind. As the button brightened in the cupel, it appeared to have a bronze color; but I have since found that when amarillium is in large excess of the gold, the button is a very dark gray. The button parted easily. To the orange solution I added a salt (NaCl) solution, shook in a silver test-bottle, and filtered. With H_2S I obtained a precipitate, which I supposed due to platinum. However, on further tests, it did

not act like a platinum-precipitate, but fused and united somewhat with the surface of the porcelain cup. On testing it further with soda I obtained a button of metal (amarillium). This strange result led me to a careful examination of the ore and a repetition of the assays, remembering the highly emphatic instructions of my talented instructor in assaying, the late Professor Fritzsche, of the Royal School of Mines, Saxony.

The ore is a friable copper carbonate, containing quite a large quantity of magnetic iron. It is probably an altered, micaceous, igneous rock, impregnated with decomposed chalcopyrite. This ore carries 1.4 ozs. of gold, 2 ozs. of silver and 3 ozs. of amarillium to the ton; so that at first, as I had only 1 oz. of the ore to work with, I had but 3 milligrams of amarillium with which to make all my determinations. I then secured 3 lbs. of the ore, from which I obtained about 160 milligrams of amarillium; but through an accident this was all lost except 14 milligrams, on which the following tests have been made. They were made September 27, 1901, and the results I communicated to Dr. Drown, of Lehigh University, Bethlehem, Pa., and to Prof. Pettee, of the University of Michigan, Ann Arbor, Mich.

I prepared the ore by dissolving out the copper in strong nitric acid, and, after the first action was over, boiled the solution low, diluted with a large amount of hot water, and filtered. I added salt (NaCl) solution to the filtrate and filtered a second time. I then burnt the two filter papers together and smelted the residue in crucibles, as I would any oxidized ore. The metal in this ore was reported by eastern assayers as platinum and palladium; but, as can be seen from the tests, it shows, also, many characteristics of cobalt and nickel, and appears like a link between these two groups.

My tests gave results as follows: At times the button appeared malleable, at others very brittle, so that I thought it might have taken up, in the course of the work, some impurity like sulphur or carbon. In the brittle state it cuts steel. It is magnetic, and, as near as I could tell from a 10-milligram button, considering the plus and minus errors, its specific gravity is 8.2. It cupels out with the precious metals, but, when alone, goes into the cupel. Also, when alone, it goes into the slag in a crucible assay. It is easily reduced with soda

by the blow-pipe; it melts into a button, but not readily, and much of it is in the form of spangles, which, however, can be collected in a button by continuing the blowing. This button gives off a white coating on the charcoal, which burns away with a bluish flame. In a borax bead, in the oxidizing flame, a small bit of the metal gives off brown streaks as it oxidizes, and finally makes the bead enamel white and opaque. In the reducing flame the bead becomes clear and has a deep cobalt blue color, but when held in the gas-light the shade of blue looks somewhat different from that of cobalt. The borax bead, reduced by tin, gives a black or dark blue color. In salt of phosphorus, in the oxidizing flame, the bead is blue, lighter than the borax bead, and in the reducing flame is crimson-lake. Of course it is possible that my button was not pure, but was alloyed with other metals, traces of copper, silver and lead being probable. In the main, these reactions are manifested in all my testing.

On examination of the ore, I found that the mineral from which this metal came occurred in arrow-head points, probably as sulphide. It is insoluble in boiling nitric acid, but soluble in *Aqua Regia*, and on heating the concentrates, sulphur is given off. As nearly as I could determine from the quantity I had, the ore appeared like sperrylite. I called it courtisite. I then carried the solution from the button through all the usual tests of qualitative analysis. I could not determine the valence of the metal, as the button seemed to have taken up carbon and left a black skeleton, which was not gold. The chemical examination shows that the metal is thrown down by H_2S in an acid solution, and that the sulphide so obtained is soluble in sodium or ammonium sulphide, from which it is precipitated by boiling, or by making the solution acid. The ammonium-sulphide solution looks like a solution of nickel. Ammonia gave a cloudy precipitate (not examined). In its other reactions the metal seems to follow platinum, precipitating on zinc, and starting a strong ebullition in a weak acid solution with zinc. There is no cobalt in it, for on dissolving in nitric acid, evaporating to dryness and taking up with hydrochloric acid, the solution still remains deep yellow.

I had not intended to publish these results at present, as I have sent to the mine for 500 lbs. of the ore on which to

make more thorough tests, but the recent discovery of what is called "josephinite," from Josephine county, Oregon, led me to believe that amarillium had been found in quantity, as the account I read described the metal as lying between platinum and nickel. I, therefore, decided to give these results as an aid to anyone in making their determinations, and establish, if I could, the fact that I had really first discovered this metal, should that reported by others prove to be identical with mine. So far this summer I have had only 9 lbs. of ore from the mine. It was a hard ore, and seemed to carry only small traces of amarillium or gold, not being the same kind as that sent before.

I expect to receive a large amount of the ore, and to furnish later results in a more carefully prepared paper.

The Ore-Deposits of the San Pedro District, New Mexico.

BY MORRISON B. YUNG AND RICHARD S. MCCAFFERY, SAN PEDRO, NEW MEXICO.

(New Haven Meeting, October, 1902.)

In the southern part of Santa Fé county, New Mexico, there are three groups of mountains, each of which penetrates the Carboniferous and Cretaceous sedimentary strata as a unit, and presents, in the main, the same characteristics and appearance. They extend in a north and south line, and, in order from the north, are the Ortiz, the Tuertos and the South mountains. The region has long been known for its mineral wealth.

The mountains present one of the features which first attract attention as one approaches the district over the plains from the east. They resemble each other so closely in appearance and height that the question naturally arises, Are not the three in some way related geologically? To the north is the Ortiz group, a cluster of sharp cone-like peaks, formed by the breaking of the eruptive syenite-porphyry through the flat beds of limestone and sandstone of the Carboniferous and Cretaceous age. These beds have been slightly lifted by the intrusion, and slope away from the mountains with a gentle and even dip. Four miles to the south is the Tuerto or San Pedro group, the geology of the western portion of which is the one

exception to the rule of this trio. This western part consists of San Pedro mountain proper, the greater part of which is formed of tilted sedimentary beds; but the eastern part of the group, including Oroquai mountain, consists entirely of the eruptive syenite-porphyry, with its sharp topography similar to the Ortiz group. Again, 3 miles farther south, is South mountain, which really includes several peaks and numerous spurs. This is also formed by an intrusion of syenite-porphyry, and shows the same topography as the first two groups.

Some miles north of the Ortiz mountains, but beyond the area of eruptives, is situated the colliery-town of Madrid, where the Colorado Fuel and Iron Co. is working beds of both bituminous and anthracite coal. In the foothills northeast of the Ortiz mountains is the ancient mining village of Dolores. On the west side of the Tuerto group is Golden, a small *adobe* town inhabited mostly by Mexicans, who work in the neighboring mines or who dry-wash the placers in the vicinity. About 2 miles south of Golden is San Pedro, built up chiefly by the development of the copper properties thereabout. Although the region has been known for a very long time, there are only a few mines which have reached any considerable development in their underground workings, so that in many cases the interpretation of the geological phenomena of the ore-deposits is difficult.

General Geology.

The general geology of the region is outlined on the accompanying map, Fig. 1, the topography being from the San Pedro sheet of the U. S. Geological Survey.

These mountains, rising from the nearly flat sedimentary plain, are formed of an eruptive rock containing both orthoclase and plagioclase feldspars. These feldspars vary in texture from porphyritic on the outskirts to granitic at the core of the igneous mass. Syenite-porphyry is the name probably best suited to it. Each group of mountains was once an enormous laccolith, but the sedimentary strata both above and around the intruded masses have been entirely eroded, so that now, with the exception of the western end of the Tuertos, there remains nothing but the igneous rock. From the

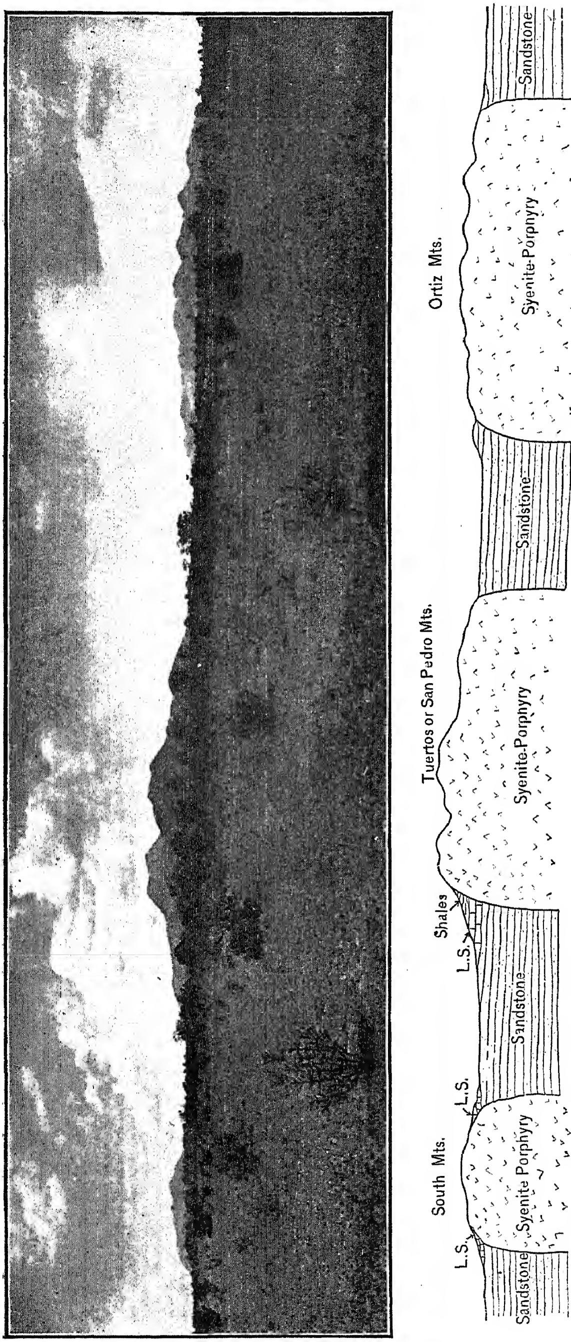
physical characteristics of these eruptive rocks it is evident that they are not surface flows, but are intrusions into the sedimentary beds. Erosion, amounting to at least 2000 ft., has gone on quite rapidly, as is shown by the present conditions, in which the soft sandstone beds of the surrounding plains are being trenched by deep *arroyos*. Just how near these intruded syenite-porphyries came to the surface it is impossible to tell, since the specimens taken from the present peaks show scarcely any difference, in the conditions of cooling, from those taken at points which must have been deep below the original surface.

Fig. 2 is a photograph of the three mountain groups taken from the eastern plains, and immediately below it is an ideal section through them. The region to the west of these groups extends for several miles in a gradually descending plain, which is cut by *arroyos* of various sizes from 6 ft. to 100 ft. in depth, and with precipitous sides. These all merge into a large central basin of a mile in width. Both in the tributary *arroyos* and in the central basin is a fine exposition of the beds composing the plain. These beds are chiefly pure sandstone, and are cut in several places by large dikes of andesite, which seem to extend toward the Ortiz mountains, although it is impossible actually to trace them thus far, as they are lost under the surface.

There are also, in the central basin, several peculiar hills composed of sandstone beds, with an igneous cap which lies conformably on the sedimentary strata, and which is responsible for the prominence of the hills. Their relative positions are such as to show, beyond a doubt, that they were once a continuous sheet, which, by faulting and erosion, has attained its present form. They face the west with abrupt cliffs of the andesite cap, below which is a talus that partially conceals the underlying sandstone strata.

The lowest of the beds yet exposed is a hard, shaly, reddish-brown sandstone, known as the "red-beds." Above this, and conformable with it, is a soft yellow sandstone 60 ft. thick; then comes an unconformity, beautifully shown in some of the north and south gulches. After the unconformity a soft red sandstone follows, above which is a soft conglomerate bed, 10 to 12 ft. thick, which seems to be a cemented placer-deposit.

FIG. 2.



Panoramic and Sectional View (on line A–A, Fig. 1) of South, Tuertos and Ortiz Mountains, San Pedro, New Mexico.

The constituents of this last vary in size from small pebbles to boulders a foot in diameter, and represent all the varieties of rock found in the neighboring mountains. Particular interest is attached to this bed on account of the values in gold which it carries. Unfortunately, these are not uniformly distributed, a condition which is necessary for the successful working of such a low-grade deposit. The gold-value varies all the way up to $2 per ton. Several companies are now testing these beds for a successful economic treatment of them, and one has erected a thirty-stamp mill.

A very interesting feature of the general geology of this region is a line of hills lying to the west of the San Pedro and South mountain groups, and extending in a northeasterly direction. They are composed of a remarkably pure bluish-white quartzite, and probably belong to the Cambrian period; at any rate, they are far older than the surrounding strata. These hills extend to the northeast as far as Golden, and, with many breaks, as far southwest as Tijeras cañon. Between this range of low hills and South mountain there is a small area of coarse pink granite, bordered in places by a typical mica schist. This pink granite closely resembles the granite forming the axis of the Sandia mountains 12 miles to the west, but no connection between the two has as yet been determined. On the west flanks of the San Pedro and South mountains are several hundred feet of Carboniferous limestone, which forms the foothills; above this, on South mountain, is a band of red sandstone which circles the entire mountain. This sandstone belt is not found on the San Pedro group of mountains, but a ove the limestone is a complicated series of baked shales and metamorphosed sediments which will be spoken of later. To the south and east of the three groups of mountains a flat plain of Cretaceous shales and sandstones extends for many miles. The northern portion of this plain contains considerable coal, and is cut by andesite dikes which seem to emanate from the Ortiz mountains. Some of these dikes are large and of very striking appearance. They rise out of the flat plain for 100 to 250 ft., and extend across the country like huge barriers. Many of them are covered with old Indian hieroglyphics.

ORE-DEPOSITS.

The ore-deposits may be divided into four classes: (1) Contact-deposits of copper; (2) Lead-silver chimneys; (3) Gold-veins; and (4) Gold-placers.

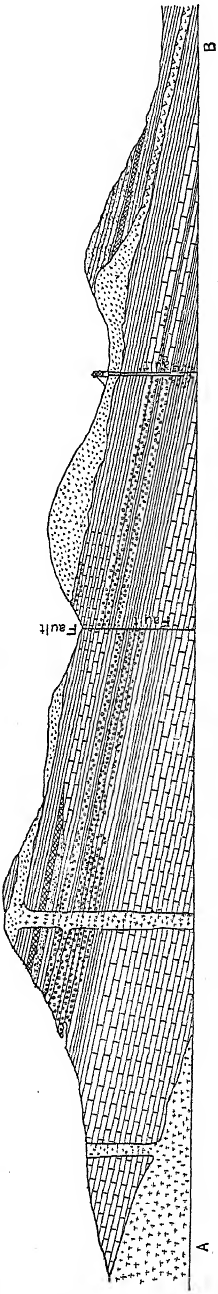
Under the first head come the deposits worked for copper in the immediate neighborhood of San Pedro. As mentioned before, the western portion of the Tuertos is formed of syenite-porphyry with a crown of limestone and shales, which are intensely metamorphosed, and which contain the copper-ores. The deposits are of the class recently described by Lindgren* as contact-deposits. The origin of the ore is certainly due to the pneumatolytic action resulting from a very forcible intrusion of a molten magma from the earth's interior among beds of limestone. Gases and vapors were liberated and caused to penetrate into the cracks and crevices of the superincumbent mass. The limestone has been replaced by massive garnet, which is in some cases 150 ft. thick. In intimate association with this garnet the ore occurs as chalcopyrite; while its associated minerals are specular hematite, epidote, vesuvianite, wollastonite, quartz, and calcite. The ore is always accompanied by garnet, although the garnet does not in all places carry ore. When the garnet carries the ore, the chalcopyrite is disseminated throughout its mass, and appears to be of synchronous origin.

Figs. 3 and 4 show the way in which the limestones and shales are underlain by the syenite-porphyry and penetrated by many andesite dikes. Closely following the contact, and but slightly above it, and also closely following the largest andesite dikes, are the mineralized zones where the limestone has been replaced by the garnet and ore. The limestone left in contact with the garnet is always more siliceous than the limestone further removed from the ore-body. A little below the outcrop, the deposit has been enriched by circulating surface-waters, but below this zone there is no evidence whatever of any such action; on the contrary, all the facts strengthen the belief that the deposit is due to the action of gases and vapors.

The intruded syenite-porphyry has entered like a wedge

* *Trans.*, xxxi., p. 226, and *Genesis of Ore-Deposits*, p. 716.

Fig. 4.



Section on line A–B of Geological Map (Fig. 3). Scale, 1 in. = 600 ft.

under the western end of the mountain, tilting the strata about 13 degrees to the east. The stratum in immediate contact with the intrusive is a limestone, varying from massive to shaly, and to the action of the syenite-porphyry on this limestone is due the formation of the ores. Above the limestone belt is a series of baked shales and calcareous sandstones, all showing the effects of metamorphism. The shales are both white and black; the black variety, owing to its hardness, forms prominent ridges which run around the hill. The sandstones also show considerable variety; there is, for example, a clear, hard sandstone composed of quartz-grains cemented by siliceous material. Then there is also an impure, fine-grained, calcareous sandstone, in which metamorphic action on the lime is plainly shown in many places by the formation of garnet, wollastonite, and other contact minerals. Lastly, there is a very coarse sandstone strongly resembling a granite. These beds are not clearly defined along their outcrops for any great distance, but, in many instances, pinch out and merge into one another.

Just above the limestone belt is an interbedded flow of andesite, which comes across the hill with the general dip of the beds. It is difficult to say just how much effect, if any, this flow has had upon the main ore-body, which lies 160 ft. below it; but it is undoubtedly responsible for numerous minor ore-bodies which have been opened up along the limestone belt just beneath it.

From the main syenite-porphyry contact on the west of the hill a dike extends to the east and appears at intervals along the crest, where it has been exposed by erosion, thus indicating the presence of the main body of the syenite-porphyry under the entire hill. The fact that a small area of the same syenite-porphyry is exposed at the eastern foot of the hill also bears out this theory.

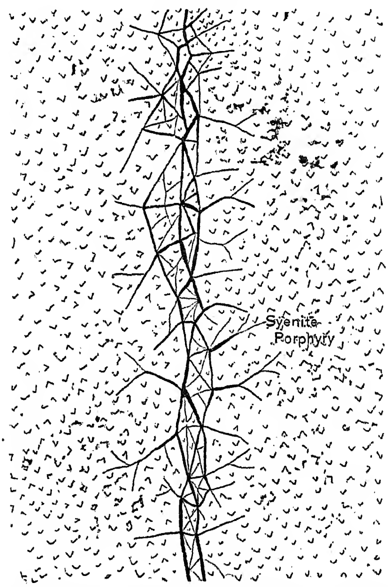
The ore-body lies in the hill conformably with the strata, and shows the greatest inequality in the distribution of the ore. It has been worked at three different levels, which are separated from each other by lean places, and not by a wall-rock. The ore carries low values in gold and silver. Oxidized ores of copper and iron are occasionally found in the deposit. There are various other minor contact-deposits on this hill, and, in every case, they occur in a mass of garnet in the vicinity of the contact of the syenite-porphyry with the limestone. They exhibit the same gangue minerals and characteristics as the deposits just described.

The second class of ore-deposits, those of lead-silver in limestones, has several representatives and has not been very important commercially. They consist of chimneys of ore which swell and pinch along a fractured zone in the limestone, which has become a channel for the circulation of underground waters. The ore consists of galena, sphalerite, alabandite, pyrite, and a small amount of chalcopyrite. There are also present cerussite, limonite and the oxidized manganese minerals. The best example of this type of deposit is the Lincoln-Lucky mine, which is on such a chute or chimney. The chute follows the dip of the limestone, and is more or less circular in cross-section and about 60 ft. in diameter. The ore was taken out by underhand stoping and hoisted on an incline through the deposit.

Under the third head come the gold-veins, which are, in number, far greater than all the other deposits combined. They may be roughly divided into deposits along crushed and fissured zones, and deposits which fill fissure-veins and are of banded structure. The first occur either in the igneous rock itself or in the sedimentary strata above it and in close proximity to it. The crushed zone usually lies in an almost vertical plane, and the general direction of these zones is east and west; they

have no definite walls, but merge into the solid country-rock. The width varies from a single fracture of an eighth of an inch to 5 or 6 ft. Quartz and pyrite have entered the shattered belts and have formed a network of cross veinlets. The gold, which is usually coarse, occurs with these minerals, and occasionally furnishes fine specimens of wire- and sheet-gold. The gold-values are contained almost entirely in the cracks and secondary veinlets, while the rock itself is practically barren. Values from 40 cents to 80 cents per ton have been obtained

FIG. 5.



Cross-section of Gold-Vein in Crushed Zone in Syenite-porphyry.

from this rock, but it is probable that these values came from vein-matter clinging to the rock-particles. The seams and veinlets will average from $30 to $60 per ton, with occasional pockets of richer values. In the oxidized parts of the veins the cracks are filled with soft gouge-matter and the pyrite is changed to the usual oxidized minerals.

There are a great number of these crushed gold-bearing zones, but they are all small, isolated, pockety, and unreliable. In spite of the fact that there has been a great deal of prospecting on this class of deposits, and considerable money ex-

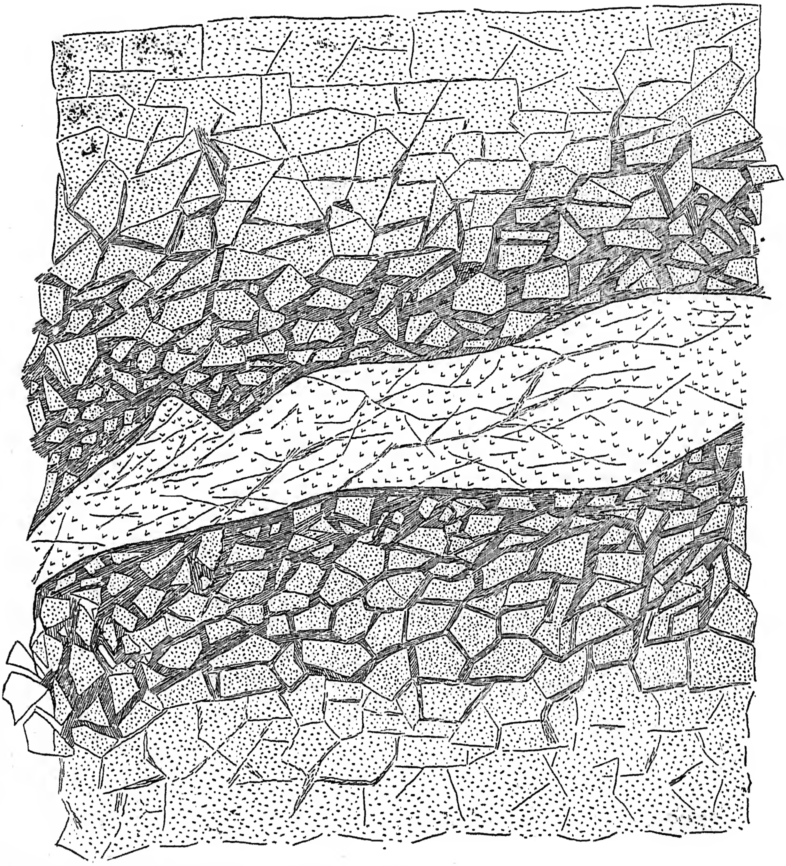
pended on mining and milling plants, no successful mine has been developed. The aggregate of the gold in these deposits is undoubtedly enormous, and they are the source of the gold in the extensive and rich placers of the district; but the gold occurs in such a way in the veins as to make their economic exploitation out of the question. Fig. 5 is the cross-section of the vein in a mine of this class in a crushed or fractured zone in the syenite-porphyry. Its width averages 4 ft., and the development of the secondary cross-veins is shown. These vary in width from an eighth of an inch to 3 in., and they carry almost the entire gold-values. Pyrite begins to come in at a depth of 100 ft. At the bottom of the shaft, where the rock is harder and the fractured zone less pronounced, the gold-values stop altogether.

Another mine, in the Ortiz mountains, shows considerable variation from this type. The hill in which the ore-bodies lie is composed of a hard, white sandstone, cut by two dikes of porphyry, which come from the main mass of the Ortiz mountains. The porphyry shows peculiar concentric discolorations, which are described by the local name "coon-tail porphyry." These dikes strike into the side of the hill, and do not reach the surface on the other side. The hill, especially at its southern end, seems to be penetrated by many intrusive sheets and dikes, which are probably offshoots from the two main dikes. The sandstones at the south end of the hill have been thoroughly shattered and cracked. Decomposition has resulted along these cracks, and has led to the formation of iron oxides and other secondary products, so that the rock looks like a coarse breccia composed of large fragments of sandstone. The southern dike, where it enters the hill, is much shattered and decomposed, and one of the principal mine-openings is at this point. The rock-fragments carry very low values, if any, while the cracks and fissures of all sizes and lengths carry considerable gold. At different places in the sandstone, where the shattering has rendered the rock easily permeable to ore-bearing solutions, rich bodies of ore are found in connection with considerable secondary quartz and oxidized iron salts. Fig. 6 is a cross-section of this deposit.

A neighboring mine closely resembles this deposit, but the igneous contact is probably more deep-seated than at the

former. It has not yet been exposed by erosion, although outcrops of the syenite-porphyry are not far distant. The ore-bearing solutions have risen along a bed of sandstone that was more porous than the adjacent beds, and the gold was deposited

Fig. 6.



Mineralized Section of Ore-Body. Syenite-porphyry shoot penetrating sandstone. Cracks in disintegrated portion are filled with iron oxide which carries gold-values.

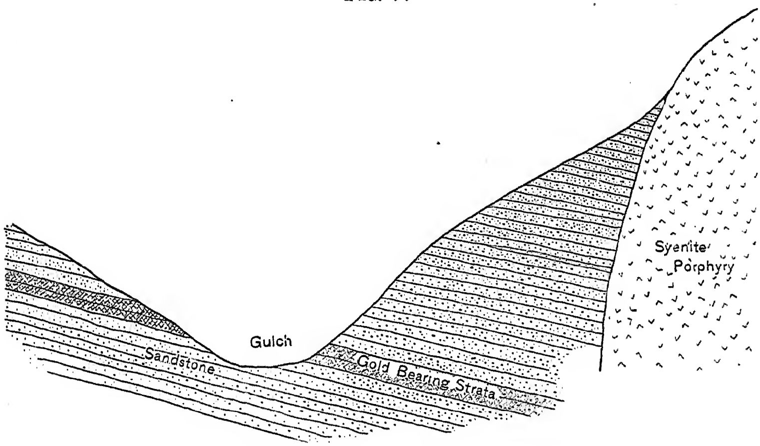
in a plane parallel to the sedimentary bedding. Fig. 7 is a cross-section through this ore-body.

The second subdivision of the gold-veins embraces the fissure-veins with banded structure. This class of deposit, with one exception, is of small importance in the district. Through-

out all three groups of mountains are found occasional small veins exhibiting a filling whose minerals are arranged in layers with comb-structure at the center. Quartz and calcite are the principal gangue minerals, and the ore is auriferous pyrite with occasional chalcopyrite. By far the best example of this class of veins is the Ortiz mine, which is a typical fissure-vein 4 to 5 ft. in width in the main mass of the syenite-porphyry. This is probably the oldest lode-mine in the United States, it having been worked by the Indians previous to the coming of the Spaniards.

Under the fourth head come the gold-placers. While the gold-veins are not, as a rule, persistent, pockets in some of them

FIG. 7.



Cross-section Showing Gold-bearing Sandstones near Igneous Contact.

have been enormously rich, and in the fan-shaped placers, at the foot of each mountain *arroyo*, is collected the gold brought down by erosion. The placer-grounds extend from the foot of the mountains in all directions for several miles, comprising in all, probably 20 to 30 sq. miles. Certain places, generally at the foot of a valley or opposite a break in the mountains, are richer than others, but all the gravel carries gold in small quantities. The gravel is very coarse at the immediate foot of the mountains, and becomes somewhat finer in the remoter portions. It varies from sand to boulders a foot in diameter, and lies from 20 to 30 ft. deep on the bed-rock. During the greater part of the year this material is perfectly dry. The

gold is mostly very coarse and little water-worn, and in many cases appears in wire and in flat scales, just as it came from the vein. The richest streak is naturally next to the bed-rock; and, judging from a great number of working-tests, this will run about $1 per cu. yd., while the surface will not average over 30 or 40 cents per cu. yd. If sufficient water could be obtained for washing, or a successful dry-washer be invented to treat the gravel on a large scale, these placers would prove immensely profitable. As it is, a great many dry-washers have been tried here with more or less success (generally less), but for one reason or another none have survived, except the small hand-machines used by the Mexicans. In these they first screen the dirt and pass the siftings over a fine inclined screen, through which is blown the air from a small centrifugal fan worked by hand. The air-blast carries the finer particles down the screen, while the heavier grains of gold are retained in shallow riffles on its upper side. The riffles are cleaned from time to time, and the resulting material is dry-panned, the result of the day's work being from 60 to 80 cents. One of these small machines will treat about a cu. yd. a day. Frequently rich strikes are made which will net the workers from $40 to $50 per week.

The authors wish to thank Professor James F. Kemp for the microscopical determination of rock specimens of this region, and are glad to say that their own independent investigations result in conclusions in accord with his views as set forth in his paper, "The Rôle of the Igneous Rocks in the Formation of Veins."*

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* *Trans.*, xxxi., p. 169, and *Genesis of Ore-Deposits*, p. 680.

The Beaumont Oil-Field, with Notes on Other Oil-Fields of the Texas Region.

BY ROBERT T. HILL, WASHINGTON, D. C.

(New York and Philadelphia Meeting, February and May, 1902.)*

INTRODUCTORY.

THE successful completion, January 10, 1901, by Capt. A. F. Lucas, of a well, near Beaumont, Texas, whereby an enormous flow, estimated at 75,000 barrels a day, was obtained, opened a new oil-field in the United States, kindled a frenzy of exploitation and speculation, revolutionized the fuel industry of a large region, and brought gain to thousands of people.

Even to-day, it is impossible to cast up the present results or to prognosticate the future influence of this event. It has caused the revival of attention in other localities where oil had been suspected, and exploration for oil throughout the Texas region. It has attracted notice to the mineral resources of the Texas region, and created an interest in the geological conditions of that great State.

This State, which has increased in population and wealth, as recorded by every succeeding census, with leaps and bounds such as are exhibited by no other part of the Union, now stands fifth in population and first in productive wealth *per capita*. Its fields, pastures, forests and mines teem with raw material. The whole economic evolution of the State has gravitated toward a focal point where these products were available for the coming of the kiln, the machine and the factory.

The only drawback to the prosperity of the State was the lack of an economic fuel, inferior coal costing an average of $5.00 per ton at the time of the Beaumont discovery. This

* SECRETARY'S NOTE.—This paper was prepared for the Franklin Institute, and presented at a joint session of the Mining and Metallurgical Section of that Society with this Institute, held May 15, 1902, at the Manufacturers' Club, Philadelphia.

prevented the successful operation of any one of the thousands of minor industries upon which other communities ordinarily depend for prosperity. As by a touch of magic, this great fuel-supply burst forth in a single day, thanks to Capt. Lucas, who, aided by the wise laws of the railway commission, placed at the fireside of every citizen, at every quarry, clay bank, sand pile, mine and mill, the cheapest and best of fuels.

With these factors in hand, who can even grasp the significance of the great industrial development which is to take place within that empire during the next decade? Who can conceive the countless wheels to be set in motion, who can reckon the prospective increase in population, the municipal development, the opening of brickyards, factories, shops and mills? Never before in history has there been such a culmination; never again will such opportunities be presented for the man of energy and means as are now presented in Texas.

The Limitations of Geological Interpretation of Oil-Phenomena.

In endeavoring to interpret the geological occurrence of oil, the geologist is confronted by the fact that science has not yet solved the problem of its origin, which lies at the root of the subject.

Among the theories in this field are those of inorganic chemical origin, resulting from reaction of one mineral upon another; the generation of oil in living microscopic organisms, such as diatoms; and the generation of oil from the decomposition and deterioration of dead organic matter, animal or vegetal, preserved in the rocks. There are facts in nature which can be made to conform to any one of these theories; but for the present we must consider oil as a material in the rocks, the origin of which is still unexplained.

Concerning this occurrence, we can only say that each field where it is discovered presents a peculiar group of data, some of which may, or may not, be presented in others. It is well-known that certain strata, like shales, with large admixture of organic matter, are nearly always more or less bituminous, and are probably the *locus* of the original formation of oil from decomposition of the organic matter. On the other hand, the oil in commercial quantities is usually found in some adjacent bed,

like an overlying stratum of sand, which forms a more porous receptacle. Where such shales and sands are in proximity, the oil is practically indigenous; and such occurrences may be termed sheet-oil. In other cases, oil is found in pockets, in strata which do not contain sufficient bituminous matter to justify the reference of its origin to them. Such occurrences may be termed pocket-oil.

Science has ascertained much concerning the underground circulation of water, but we know very little concerning the laws controlling the underground circulation of oil. The few elementary physical facts concerning the behavior of oil and water teach us some lessons. From the antithetic behavior of the water and the oil upon the surface, we can with safety presume that these substances will not act in an entirely harmonious manner underground. We know that oil will float upon water, and therefore that circulating underground waters, if ascending, may gather oil from places of its origin, and transport it and store it in remote underground reservoirs. On the other hand, oil differs from water in capacity for permeation and osmosis. Oil stored in a tightly-sealed bottle will pass by osmosis through the glass more rapidly than water. The question of the underground migration of oil is one of the profound fields for future research.

The principal deductions from the world's experience concerning the occurrence of oil are:

1. The chemical origin of oil is as yet unexplained.

2. Oil may occur in stratified rocks of any age from the oldest Paleozoic (as in Pennsylvania) to the latest Tertiary (as in Texas).

3. Oil usually occurs in terrigenous (land-derived) marine deposits, such as sands and clays, in which there is a mixture of organic matter, and is not common in rocks of deeper-sea origin, such as many of the foraminiferal limestones, or igneous rocks.

4. The circulation of oil in rocks is different from that of water.

5. The structure or arrangement of the rocks influences the collection and storage of oil; and hence the knowledge of geological structure aids in the determination of favorable or unfavorable conditions for the underground storage of oil.

6. Some underground bodies of oil are known to be stored in, or even to be derived from, definite strata. The trained geologist can indicate the underground extent ("embed") of such strata.

7. Other underground oils are stored in favorable *loci* more or less remote from the strata in which they originated, and accumulated in folds or pockets, like water in a rubber blanket (the blanket being inverted).

The above facts indicate what the geologist can and cannot tell concerning oil-fields. The first thing he can do in the great region is to eliminate or cancel broad areas of unfavorable strata, leaving certains fields of probability and improbability. Within a determined field of probability it is impossible to predict the actual point where oil can be found. The cost and credit of developing the oil-field must always ultimately fall upon those who boldly risk labor and money upon what is largely a game of chance.

The practical geologist has to deal primarily with the stratigraphic location of oil; the deformations of strata favoring the collection of this oil in geological receptacles; and the laws of underground circulation of oil in the rocks.

Where a determined oil-field is underlaid by sheet-oil, the probabilities of success are greater, and the geologist can assist the practical man with some confidence. On the other hand, where the oil-field consists of pockets, no one knows as yet how to locate these pockets beneath the surface.

The oil-bearing strata of the Beaumont oils are entirely different from those of the Corsicana oil-field (where the oils are derived from the Upper Cretaceous strata); from the Indian Territory oil-fields (where the oils are derived from the Carboniferous strata); and from the oil-fields of Pennsylvania, Ohio and West Virginia (which receive their oil from the still older Paleozoic rocks, such as the Trenton).

The prospector in the Beaumont oil-field must be prepared to cast aside previous conceptions based upon the structure and age of the earlier-known oil-fields.

Geography of the Texas Region.

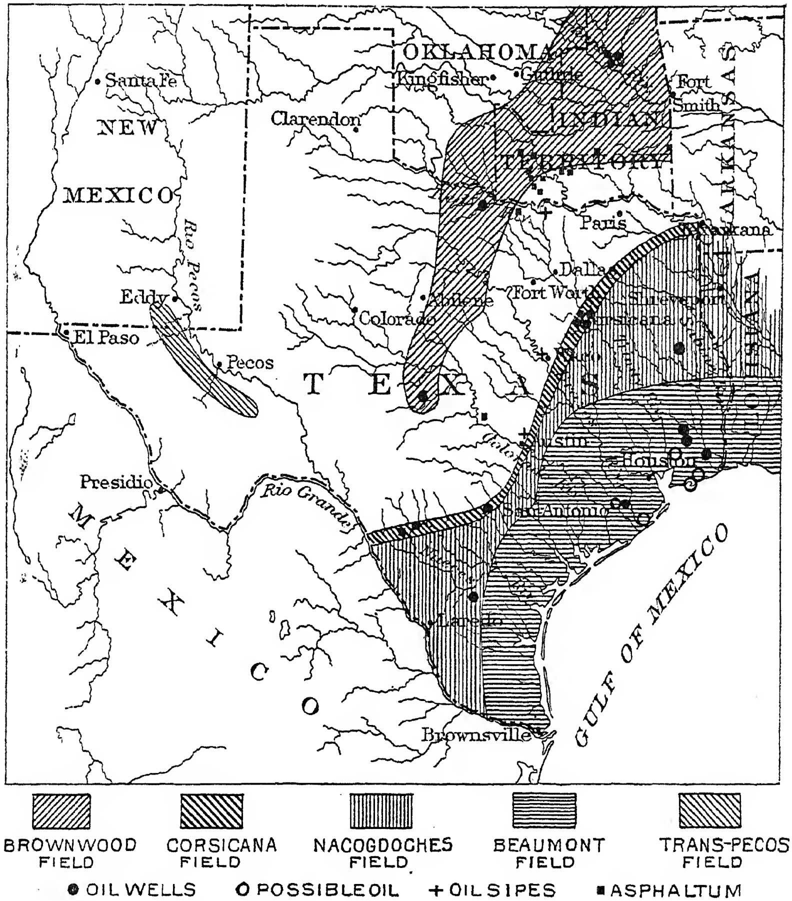
In a recent paper* the author presented an outline of the physiographic features of the Texas region, as shown on a map

* *Topog. Atlas of the U. S., Folio* 3; *Phys. Geog. of the Texas Region, U. S. G. S.*, 1900.

therewith, and defined its earliest primary natural subdivisions, as a basis for more detailed discussion and differentiation of the various phenomena.

The Greater Texas region includes, practically, all the country

Fig. 1.



Map of the Texas Oil-Region and adjacent Oil-bearing Territory.

east of the Rio Grande and south of the northern boundary of New Mexico. The area thus defined consists of a peculiar group of physiographic units, composed of mountains and plains belonging to the four greater natural provinces of the United States, to wit: the Cordilleran region, the Great Plain region,

the Appalachian region, and the Atlantic Coastal Plain. The characteristic features of these regions as they extend into the State present local modifications. There are also in the central portion extensive stretches of country which have no counterpart elsewhere.

It is impossible to give here the details of the varied geographical features of this vast area, which includes nearly one-tenth (Texas proper embracing one-twelfth) of the present area of the United States. In another paper* I showed the rapid evolution which the economic features of Texas have undergone in the past twenty years from the pastoral to the industrial conditions, and declared that the one great need of the State was an economic fuel. Almost coincident with the publication of that paper was the completion of the great oil-wells at Beaumont.

The already ascertained oil-yielding territory of the State with its probable extension into adjacent States is indicated on accompanying sketch map, Fig. 1.

Sedimentary Rocks of the Texas Region Connected with the Oil-Problem.

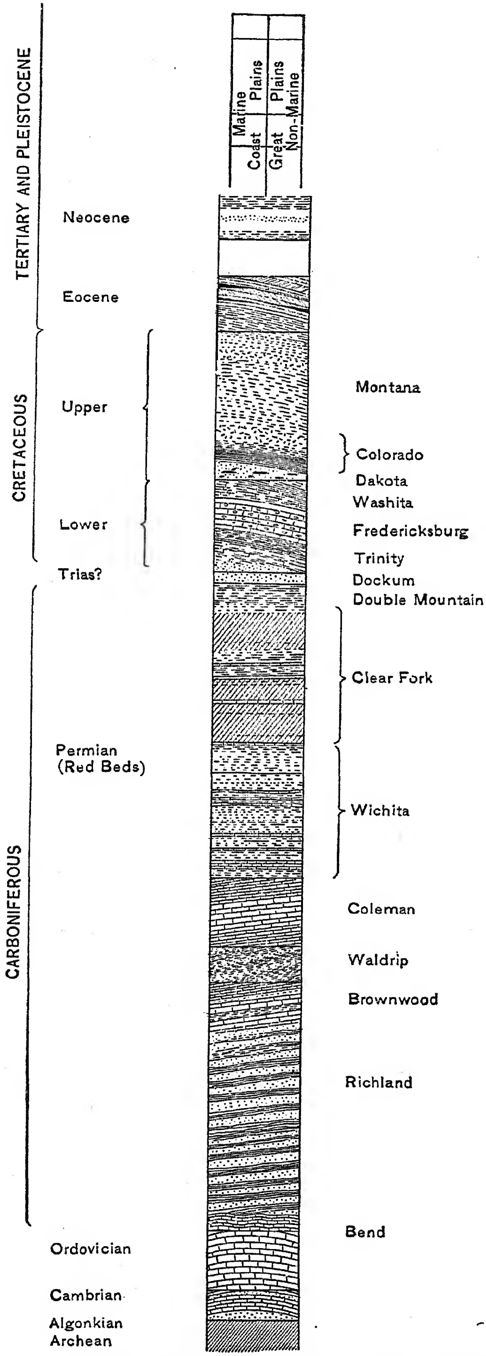
Most of the surface of Texas is formed of sedimentary rocks, igneous formations covering a smaller area. There are also extensive formations composed of wind-blown *débris*, chemical precipitates, and upland drift.

The sedimentary rocks are alone pertinent to the present paper. They lie one above another in more or less orderly succession, and are of two general classes: (1) marine formations, originally laid down upon the marginal bottoms of the sea; (2) superficial formations, deposited upon the slopes of the land or at local deposition-levels, such as lakes, rivers or other bodies of water within the land-area.

The marine sedimentary rocks laid down on the sea-bottoms are of all ages from Cambrian to Recent, with the possible exception of the Devonian. They aggregate about 25,000 feet in thickness, as shown in the vertical section, Fig. 2. The strata vary in hardness; are tilted steeply in the mountainous areas,

* See *Forum*, August, 1900, and *Encyclopædia Britannica, London Times Supplement*, 1902.

FIG. 2.



Section showing the geology of the Texas region.

and are nearly horizontal in the plains. They are of two general classes, differing in occurrence and importance:

1. An older or fundamental series of Paleozoic formations. The structural arrangement of these formations in anticlines and synclines is discordant with that of the later formations of the Coastward Slope. The series represents the remains of an ancient topography, which was base-leveled during Jurassic and Cretaceous time, prior to the invasion of the Cretaceous seas, which completely buried it with later sediments. These older rocks, except in the mountains, are now seen only where areas of the later strata have been worn away. In the structure of this group is written an interesting pre-Cretaceous history, involving the growth and decay of relief-features quite different in detail from those of the present time.

2. Formations of the Coastward Slope from Cretaceous to Recent age. Most of these rocks were once marginal deposits of the Gulf of Mexico, laid down when it extended much farther inland than it does to-day; and they were elevated as the Gulf receded from the Rocky Mountain front to its present position. All these strata now incline toward the sea. In some instances the inclination coincides with the surface-slope, while in others it is slightly greater.

The Paleozoic rocks may be divided into two groups—the earlier and the later Paleozoic. The first includes the Cambrian and Ordovician; the second, the Carboniferous and Permian, or Permo-Triassic. The same names characterize four primary lithologic subdivisions. Of these, the first two are usually more or less associated in geographic occurrence in limited areas, and by reason of their hardness produce allied features of topographic relief. The third and fourth, forming the surfaces of large areas, have each individual features.

The pre-Cambrian and older Paleozoic rocks are the foundations upon which all the other rocks were laid down, and are still, in the main, covered by them. Their outcrops are exceptional and restricted in area; they occur in small districts in the Wichita range of the Ouachita mountain system, in some of the trans-Pecos mountains, especially between the 31st and 32d parallels, and in a limited territory in the southern end of the Central Province, known as the Burnet country.

The Cambro-Silurian rocks are indurated clays, sandstones,

and limestones. They usually occur in geographic association with the pre-Cambrian and Carboniferous rocks, in the southern part of the Indian Territory and central Texas.

The Carboniferous rocks are the chief formations of the Ouachita mountains, the eastern border of the Central Province in Indian Territory and Texas, and certain mountains of trans-Pecos, Texas. The Permian, or Red Beds, prevail in the greater part of the Central Province and in the Pecos and Canadian valleys. The Carboniferous and Permian rocks produce somewhat allied but different topographic forms. The Carboniferous (east of the Pecos), largely made up of soft, impure shales, alternating with harder, coarse brown sandstones and conglomerates, produces ridge-like mountains and a broken belt of country along the eastern margin of the Central Province, called "flats." The Permian Red Beds, some 7000 ft. in thickness, consist largely of unindurated arenaceous clays, with only a few hard strata. They weather into extensive flat regions with occasional scarp-lines attended by "bad-land" slopes. They occupy the western and greater part of the Central Province, extend beneath the Plateau of the Plains, and outcrop in Pecos valley against the eastern front of the Cordilleras.

The existence of the early Mesozoic (Triassic) is doubtful, although possible. Rocks referred to this period overlie the Permian along the western part of the Central Province, and appear in small areas around the border of the Plateau of the Plains, but are not pertinent to our present subject. Jurassic limestone strata of the Mexican type have been found in only a limited area in the basin-ranges of the interior desert, west of the Cordilleran front, and are not known on the Atlantic slope or in the series of the Texas Coastal Plain.

The Coastward Gulf slope consists of vast sheets of sea-made sediments, from Cretaceous to Pleistocene age, inclusive, and of aggradational deposits of upland wash, and stream and lacustral alluvium of Tertiary and later age, all of which, except the Lower Cretaceous, are mostly unconsolidated terranes of clay, sand, marl, and loam. Of this later group, the marine Cretaceous, Tertiary and Pleistocene rocks are the chief formations, especially east and south of the Central Province. These rocks occur in belts sub-parallel to the coast.

The Cretaceous rocks are divisible into an older or lower and a newer or upper series. They occur along the western border of the Coastward Slope plain. The older formations consist of hard limestones alternating with clays, and are underlaid by sands; they produce dip plains, cut plains, and low scarps. The Upper Cretaceous strata consist largely of unindurated clay marls, with a few indurated scarp-making strata all underlaid by sands, and weathering into low, undulating areas.

These Cretaceous strata, underlying the Coastal Plain of Texas, in the Black and Grand Prairie countries, have been minutely described by the writer in many papers, especially Part VII. of the Twenty-first Annual Report of the Director of the United States Geological Survey. These consist of nearly four thousand feet of shales and sands, and limestones; probably one-half of the section is made up of marine near-shore clays and sands, and the remainder of deeper water limestones. The Cretaceous strata constitute the floor or foundation upon which the Tertiary and Pleistocene sediments were deposited, and most probably underlie the whole Coastal Plain of Texas, at great depth, their base being not less than 10,000 feet deep along the coast at Galveston.

For present purposes the Tertiary may be divided into two great groups, a lower and an upper, which may be termed the Eocene and Neocene respectively.

The Eocene strata consist of a series of unconsolidated sands and clays, accompanied by fossil shells and beds of lignite, and about 3000 ft., more or less, in thickness. They have been considerably studied in a manner to make known their stratigraphy and character; but the nomenclature and classification are still susceptible of refinement. The writer prefers for the present to divide the rocks of the epoch into two series. For the older, including all the rocks from the base to the Nacogdoches oil-formation, he has already used the name Camden series. For the rocks above the horizon, the term Angelina may be used. While paleontologists are disagreed in their determinations, these names are good for tentative use.

The Camden series includes many beds of clays, sand and lignite (underlying the East Texas timber-belt), for which various names have been proposed.*

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* See various reports of the Texas *State Geological Survey.*

The Angelina series, above the so-called marine beds of the Camden series, which are the first classified deposits immediately north of the Beaumont oil-field, have been described by Kennedy, in descending order, as follows:

1. The Lufkin deposits (Yegua), made up chiefly of dark-blue gypseous clays, and gray sands containing quantities of saline matter. These beds also contain lignite, in many places, in beds or deposits of considerable extent.

2. The Fayette sands, made up of soft sandstones, light-colored clays, sandy clays, and sands with occasional remains of vegetable life. These deposits approach in texture and mode of occurrence the typical Grand Gulf formations, as described by Hilgard, in Mississippi, and by Hopkins, in Louisiana. The plant-remains, such as palms, etc., are also in close correspondence.

3. The Fleming beds (Frio clays) consist of heavy deposits of clays of various colors, some of them containing concretions of lime, and gray sands. The plant-remains of these sands are chiefly wood, and often occur in large pieces and considerable quantities. The Frio clays are considered Eocene in Kennedy's later publications.

The sections made by Kennedy give the general character and sequence of the formations along a general section from Nacogdoches county to the Gulf.*

The thickness of the later Eocene (Angelina series) sections, as given by Kennedy, aggregates 1407 ft.

Above the Frio clays of supposed Eocene age follows a series of unconsolidated sands and clays of Neocene, Pleistocene and Recent age, which constitute the formations of the Coast Prairie. These will be further discussed on a succeeding page, under the head of the *X* beds.

Summarized, the post-Carboniferous strata beneath the Central Plain of Texas, and which by dip should be beneath the Coast Prairie, are as follows:

	Ft.
Post-Eocene,	1000 to 2,500
Eocene,	3,500
Upper Cretaceous,	2,000
Lower Cretaceous,	2,000
Total,	10,000

* *Third Annual Rep. Geol. Surv. Texas*, 1891, "A Section from Terrell, Kaufman county, to Sabine Pass on the Gulf of Mexico," by Wm. Kennedy, pp. 53, 55, 61, 62, 63.

Structure of the Sedimentary Rock-Sheets.

In general, the Paleozoic rocks of the northern border of the Ouachita mountains of Indian Territory and the mountains of trans-Pecos, Texas, are greatly tilted as a result of the Appalachian revolution. Between the mountains the Paleozoic rocks in Texas occupy a great synclinal basin, dipping westward from their exposed eastern outcrops, and eastward from their exposed western outcrops.

Over this synclinal basin, after a long land-period, the rocks of the coastal-plain, from the base of the Cretaceous upward, were laid down unconformably. This unconformity is the most radical structural feature in the whole Texas sequence. It is not necessary for our present purpose to go further into the details of the structure of the Paleozoic rocks.

As a whole, these Cretaceous and Tertiary rock-sheets of the Texas Coastal Plain may be collectively discussed as the systems of the coastward incline, and their structure is very simple; the strata being characterized by their unconsolidated nature, their regularity of sequence, simplicity of arrangement, and gentle dip coastward.

One who begins at the coast and travels across this region, along any line radial to the coast, will find that, while the surface constantly ascends above the level of the sea at a slight gradient, it presents a descending geologic sequence in successive belts of country, each with its peculiar soil, rock, and flora, due to the differences in the rock-sheets of which it is formed. The outcrops of the various strata, owing to their physical and chemical composition, have weathered into diverse characters of country—forest and prairie, broken or level—exactly as the substructure permits.

There are few, if any, breaks in the continuity of deposition of the 10,000 ft. of sediments, of Cretaceous and later age, constituting the coastward incline. One of these apparently occurred at the middle of the Cretaceous, but without any special stratigraphic discordance. Another is supposed to have taken place at the close of the Cretaceous, but is not proved.

According to Kennedy, at the close of the period occupied by the deposition of the last of the marine beds of the Eocene, a break of considerable extent occurred; and extensive erosion, implying elevation, appears to have taken place prior to the de-

position of the succeeding deposits. Strong proof of this erosion can be seen almost anywhere along the line of contact, where the succeeding denudation has carried off the overlying mantle of sand and gravel of the Angelina series. He says that this want of conformity is everywhere visible, and the clays and sands of the Grand Gulf frequently extend in long narrow strips for several miles into the region occupied by the Eocene marine formations, and at other places are found bold headlands made up of the deposits of that age. Kennedy also informs the writer that there is a similar break at the top of the Angelina series.

So far as known, there are no strong folds or basins in the strata of the Coastal Plain, such as exist in the Ohio and Pennsylvania oil-fields, although there are probably some very low anticlines or swells, which materially bear upon the storage of the oil in reservoirs, or oil-containing strata. In general, the structure of the Coastal Plain is monotonously monoclinal.

The formations of the Coastal Plain are all marginal sediments of the Gulf of Mexico; and the present tilt coastward may be considered the algebraic sum of several periods of elevation and subsidence since the beginning of Cretaceous time, the net result of which is a sinking of over 10,000 ft. at the present coast-line.

It is well known that in the epochs from the Pliocene to the present there have been several movements of elevation and subsidence, during which the shore-line of the Gulf of Mexico migrated back and forth. At times this shore-line was far inward from its present site, while at other times it may have been considerably seaward.

It is also probable that the stress resulting from the vertical movements of these strata caused faults, some of which are already known to have taken place along the western margin of the Coastal Plain.

Oil-Fields of the Texas Region.*

While the phenomena of the Beaumont field have attracted great attention, many are not aware of the fact that in the State of Texas there are several other oil-fields (productive or prospective) entirely distinct from the Beaumont field, and from one

* See also *Bulletin U. S. Geological Survey*, No. 184, by George I. Adams, Washington, 1901.

another, in geological and geographical conditions. One of these has been productive for many years, while the others may some day give profitable returns.

One of these fields is already a large producer of a high-grade illuminating oil, supplying nearly 1,000,000 barrels per year of oil as good as that of the Washington county, Pa., field. There are also many localities where bitumen occurs as asphaltum.

The typical oil and asphaltum horizons of Texas are as follows:

The Beaumont.
Nacogdoches.
Corsicana-San Antonio (Uvalde asphalt).
The St. Jo (asphalt).
The Brownwood-Henrietta.
The Trans-Pecos.
The Buckhorn (asphalt).

Of these, one asphalt-field is found in the Ordovician rocks; two oil-fields (the Brownwood-Henrietta and the Trans-Pecos) in the older (Carboniferous) rocks of the Coastal Plain; and the others in the Cretaceous and Tertiary. I shall briefly describe each of these fields in ascending stratigraphic order, which also corresponds to their relative importance.

In the southern Indian Territory there are, in Ordovician and Carboniferous formations, many asphalt springs and bituminous rocks which show the presence of a great amount of bituminous material. These asphaltic deposits have been recently described in detail by the United States Geological Survey in a paper entitled "The Asphalt and Bituminous Rock Deposits of the United States," by George H. Eldridge.*

The Pecos Oil-Field.

In Reeves, Pecos and El Paso counties, Texas, and in Eddy, Otero and Chaves counties, of southeastern New Mexico, there is a prospective field in which many "seeps" have been found, and oil in small quantities has been struck in wells. This region lies immediately west of the Pecos river, and extends north of the Southern Pacific R. R., far into southern New Mexico, and adjacent to the eastern slope of the Guadaloupe mountain uplift.

* See 22*d Annual Report of the Director of the U. S. Geological Survey*, 1900–1901, Part I., p. 209.

The geological series seems to have, primarily, a great thickness of indurated Carboniferous limestones at the base; then a series of sands and bituminous shales; then another vast thickness of Upper Carboniferous and Permian limestones; then shales and clays of Permian or Triassic age; then the basement sands and limestones of the Comanche Cretaceous; the whole being largely obscured toward the Pecos valley by large quantities of wash and desert *débris*. The geological structure consists of a long monoclinal uplift dipping, from the western crest of the Guadaloupe-Sacramento range and the Comanche range, eastward toward the Pecos river. This monocline is waved by numerous secondary anticlines and synclines, and steep faults to the west. By reason of the ease with which the many low secondary anticlines and synclines can be made out, this structure is apparently more propitious for the location and extraction of oil than that of any other Texas field.

Most of this area lies upon the eastern slope of the monoclinal mountains of the Comanche and Guadaloupe-Sacramento range. A few oil-indications have been found further west, in the Salt Basin flat.

Within the area mentioned, oil, asphaltum and sulphur have been encountered at numerous places in wells or springs, and upon the surface; and while the region has not yet been minutely studied, there is every indication that by scientific study and exploration it can be developed into an oil-field. Unfortunately, the only drawback, up to date, is the fact that the oil thus far encountered is of a very inferior quality, containing, as shown by Prof. Phillips,* a residue of 45 per cent. of asphaltic material, and only about 25 per cent. of all grades of illuminants.

The Henrietta-Brownwood Field.

In this field, coincident with the Carboniferous outcrops in northern central Texas and the southern Indian Territory, numerous finds of oil have been made in small quantities, notably at Henrietta, Clay county, and in Brown and Coleman counties.

These Carboniferous formations are of great thickness (over

* *Bulletins Nos.* 1 *and* 2 *of the Mineral Survey of Texas,* Austin, Tex., 1901, 1902.

7000 ft. in Texas), and apparently contain many oil-bearing horizons. They also furnish some of the maltha springs of the Chickasaw Nation in the Indian Territory, and the oil and gas of the northern Indian Territory and Kansas. No oil in commercial quantities has as yet been found in this field; but the quality of that hitherto found has been good. Exploitation is proceeding rapidly.

Bituminous Horizons in the Base of the Cretaceous.

The basement-beds of the Comanche series of Texas and the southern Indian Territory are bituminous in several places, notably between Emmet and Caddo, I. T.; at Matubby springs, about 5 m. NW. of Caddo; at Oakland, 16 m. SW. of Emmet; and at Marietta.* At these localities the basement-sand of the Cretaceous is impregnated horizontally. Crossing Red river to the southward, rich bituminous impregnations are similarly found in the basement-sands near St. Jo, Montague county. Some 200 m. further S., in Burnet county, asphalt is again found in the vicinity of the town of Burnet, impregnating small breccia at the base of the Cretaceous.

There are several minor beds of shale and clay in the Cretaceous, which have furnished traces of petroleum and asphalt. A mile or two west of Austin, a little petroleum was found in the Del Rio clays. Traces of petroleum have frequently been found in the Eagle Ford shales, notably at Watter's station, N. of Austin, and in the NW. in Grayson county, on Red river.

The Corsicana Oil-Field.

Since 1891, illuminating oil has been produced in the vicinity of Corsicana, where the Standard Oil Co. has had a refinery. In 1900, the production of this district was 829,560 bbls. The oil is of fine quality, analogous to that of the Washington county, Pa., field, and has a paraffine base. The wells are not gushers, but are pumped from depths averaging about 1100 ft.

Unlike the oil of the Beaumont field, that of Corsicana is distinctly a sheet-oil, that is, it occurs in a definite geological stratum, namely, a horizon in the bituminous sandy clay shales of the Navarro beds, of the upper portion of the Gulf series of

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* See paper by Eldridge, previously cited.

the Cretaceous. The geological position is closely near that of the Florence and Boulder oil-fields of Colorado.

An interesting feature of the Corsicana field is the fact that the Upper Cretaceous strata from which the oils are derived contain at least two distinct oil-bearing horizons; the uppermost has an asphaltum base, while the lower is of a paraffine nature. The upper bed is encountered at Powell, about 20 m. E. of Corsicana; and I estimate that it is from 500 to 1000 ft. above the lower, which supplies the Corsicana wells.

These strata extend, with very slight variation, completely across Texas, from near Boston on Red river to near Eagle Pass on the Rio Grande, in a curved line 750 m. long. An oil-asphaltum has been found in them at several places, notably a trace in the well at Bremond; a trace in eastern Travis county; near Elgin, near Lytton in Caldwell county; a few miles east of San Antonio; and on the Sabinal in Medina county. The asphaltum-beds of Uvalde and Kinney counties are derived from practically the same strata. It is the writer's opinion that when the continuity of this bituminous formation across the State has been fully appreciated and exploited in a scientific manner, many productive spots, similar to the Corsicana basin, may be found.

The Nacogdoches Oil-Field.

A number of years ago, oil was struck at shallow depths in wells in southern Nacogdoches county, about 100 m. W. of N. from Beaumont. According to the studies of various geologists, the horizon of this oil-field is near the top of the Claiborne Eocene of the Tertiary.

A fine-grained quartz-sand, saturated with oil, which on the outcrop is a semi-asphalt, is apparently the source of the oil. It lies immediately below a green horizon, the outcrop of which is easily traceable by its blood-red soil, a product of the oxidation of glauconite.

Since the discovery of oil at Beaumont, renewed interest has been awakened in Nacogdoches, and several wells are being drilled.

At many other localities throughout the outcrop of the Eocene Tertiary of Texas, traces of oil have been found. Much interest is now shown in the vicinity of Sutherland Springs,

Wilson county. A good oil is also reported 14 m. S. of Campbellton, near the junction of Atascosa, McMullen and Live Oak counties.

THE BEAUMONT OIL-FIELD.

This name the writer prefers to use for the oil-producing district within the area of the Coast Prairie of the Texas, Louisiana and Mexican region.

Discovery.—Before the first white man came, it was known that oil existed in small quantities in western Louisiana and Texas, within 100 m., more or less, of the present site of Beaumont. It was a matter of rumor for many years that oil floated upon the sea just W. of Port Sabine. Petroleum springs existed at several places, notably Lake Charles, Louisiana. It had also been encountered in the well-borings in western Louisiana, E. of Beaumont. As early as 1862, unprofitable attempts at drilling had been made at Sour Lake. Even at Beaumont, similar attempts failed. Until 1901, no man had obtained the oil in commercial quantities.

The finding of oil at Beaumont was not an accident, but, like all other great discoveries, the dramatic culmination of long and extensive research and many experiments, each of which was an important factor in the final result. Capt. A. F. Lucas, to whom the glory of the crowning achievement is fairly due, had been, since 1892, carefully studying the geology of the coastal plain of western Louisiana and eastern Texas, with the view of developing its salt, sulphur, and petroleum. With the aid of every recorded observation which he could obtain, supplemented by his own experience and reasoning, he concluded that the structure and stratigraphy of Beaumont gave the best prospect of oil. Previous failures at this place were, in his judgment, due to mechanical difficulties, which could be overcome—an opinion which he fully confirmed by his work.

Capt. Lucas, a native of Austria, and graduate of the Polytechnic School of Gratz and of the Imperial Austrian naval school, had been for some ten years actively engaged in this country as a mining engineer, especially in the development and operation of the salt-mines of Louisiana.*

* See his paper on "Rock-Salt in Louisiana," *Trans.*, xxix., 462.

In connection with this work, he found in one or two places indications of oil, and also of sulphur (of the existence of which, in that region, the famous Calcasieu deposit is a proof). Conceiving the plan of a systematic exploration for oil, he finally chose Beaumont, Texas, as the scene of operations. His first well, begun in 1899, was 575 ft. deep in March, 1900, and showed a trace of oil at the bottom, when the casing broke, and the well had to be abandoned. Not daunted, he commenced in October, 1900, another well beside the old one. The public will never realize the obstacles and difficulties which had to be overcome. One of Capt. Lucas's greatest technical achievements was the putting of a drill-hole through 1100 ft. of clay and quicksand. The methods and contrivances used by him made possible the other wells which have followed. This second well, which "came in" Jan. 19, 1901, was the famous "Lucas Gusher."

Economic Conditions.—The Beaumont oil, when first discovered, was found to be of a different quality from that of any other field, and many doubts arose as to its value and uses. Having a heavy base of asphaltum, and being thoroughly impregnated with sulphur, it was supposed to have no value as an illuminant, and many believed that the excess of sulphur would so corrode boilers that it could not be used as a fuel. This sulphur was so apparent that on occasions, as on March 4, 1902, it filled the atmosphere, leaving a coating of sulphur on many of the houses in Beaumont, some 3 m. from the oil-field.

The chemical analysis of the oil is as follows:

Composition of Beaumont Oil. From Chemical Analyses by Prof. F. C. Thiele.

I.

	Per cent.
Kerosene,	36.00
Light lubricating oil,	21.05
Medium lubricating oil,	21.05
Heavy lubricating oil,	10.52
Asphalt,	6.34
Loss and gases, including sulphur,	5.04
	100.00

Color of crude oil: brown, opaque.

Sp. Grav., 0.9206; equivalent to 22° B. at 62.57° Fahr.

II.

Naphtha,	6 45
Kerosene,	35.00
Lubricating oil,	43.90
Residue and gases,	14.65
	100.00

Test of obtained kerosene :

Color,	Prime white.
Sp. Grav.,	0.872, equivalent to 30° B. at 65.5° Fahr.
Flash-point,	120° Fahr.
Fire-test,	150° "

It was soon realized that, if fit for no other uses, this was an excellent fuel. After a year of experiment, it is now generally conceded that the oil has many excellent qualities, and that, after refining for the kerosenes, the remainder is as good a fuel and gas-making material as can be desired. Upon the basis of elaborate refinery, chemical and fuel-tests, made on large quantities, the following facts may be stated as established: (1) The Beaumont oil has a low flash-point of 120° Fahr., which renders it an unsafe, or at least undesirable, cargo in tank-ships; (2) refined by first distillation, it produces 30 per cent. of export illuminating-oil, leaving a residuum of good fuel-oil, which can be transported with perfect safety; (3) the sulphur can be extracted if necessary, but when left in the oil has no injurious effect whatever upon the boilers, while it adds to the fuel value; (4) as a fuel, three barrels of this oil can be delivered by rail in any city in Texas at a price of $2.70, the price of bituminous coal being $5, and that of anthracite coal $10 per ton. The oil may be laid down in New York, Philadelphia or Boston at 75 cents a barrel.

The flash-point of the crude oil is too low for marine insurance, but this defect can be obviated by a profitable preliminary refining, whereby the naphtha and kerosene are extracted, and the flash-point is raised to a standard for safe shipment.

Immediately after the discovery at Spindle Top every acre within 50 m. was leased, and wells were started everywhere. Since it then took from three to six months to put down one of these costly wells, some time was required to show by experiment that all the oil in the immediate vicinity of Beaumont

was confined to Spindle Top hill, within an area of less than 300 acres.*

This was at first seriously discouraging. Many thought that if the oil was confined to this one small locality it would soon be exhausted, and the business would be at an end. Prudent operators at Spindle Top did not feel justified in making long-time contracts; and railways and factories, with the risk of an exhausted supply before them, naturally hesitated to make the expensive changes required for the use of this fuel.

The "coming in" of Jennings, Sour Lake and Saratoga removed the fear of inadequate supply; and no one now apprehends an early cessation of production, even if Spindle Top should soon be exhausted, which has not been proved probable.

When the Beaumont well was discovered, the writer, aware that similar conditions existed over a wide area, ventured the following prophecy:

"It is entirely within the limit of probability that oil will be found at many places throughout the Coastal Prairie, especially in its southern extension toward the Rio Grande and in the northeastern State of Mexico at Tamaulipas. The outcrop of the Tertiary formations in southwest Texas, in Wilson, Atascosa, McMullen, Duval and other counties, is naturally rich in oil; and the practical oil-men are risking their money in experimenting in this region. As the oil-bearing Tertiary strata extend east of the Mississippi into Mississippi and Alabama, it is not beyond possibility that oil may be found in these States."

The following data, showing the results of one year's exploitation, sufficiently confirm this declaration, which was received at that time with incredulity:

At Jennings, Louisiana, 150 m. east of Beaumont, a good flow of oil has been encountered. This well is 1830 ft. deep, and is described as a mild sort of "gusher." In the morning it spouts about 35 ft., and at other times just high enough to make a good flow. Although this oil is accompanied by a great deal of sand which chokes up the well, it demonstrates the broad geological fact which I asserted. Practical oil-men have such faith in the locality that a dozen or more well-rigs

* The exact extent of the productive ground of Spindle Top hill has not yet been determined, because several of the largest corporations own large tracts on one side of the hill, where the limits have not been exploited. It is known that this field certainly exceeds 200 acres; and most of the oil-men think it will reach 300 or 325 acres. It is still occasionally widened by new wells.

are at work. The sand-problem is a mechanical difficulty which all are confident will be overcome.

Proceeding west from Jennings toward Beaumont, oil has been found in varying quantities at Lake Charles, near Crowley, and in one or two other places.

At Sour Lake, 25 m. NW. of Beaumont, oil has been known to exist since 1862; and a dozen years ago many pumping-wells were operated, and a small refinery was established. The field was abandoned; but after the Beaumont discovery numerous well-rigs were set up to penetrate to greater depths. From seven to eleven different oil-strata were passed through, and in August, 1901, a well, similar to that at Jennings, was obtained by the Guffey people. Its product has not been reported.

On March 7, 1902, another great oil-strike was made at Sour Lake, at a depth of 685 ft., by the Atlantic and Pacific Company. It is said that the oil shot 150 ft. into the air, and was of better quality than that at Beaumont.

Twelve miles N. of Sour Lake, at the village of Saratoga, where the oil outcrops at the surface as maltha, it is said that a good oil-well has been obtained, flowing several thousand barrels per day.

Rockland, N. of Saratoga, is the next place where oil-deposits are found, and experimental boring has been going on here for some time. The sand-rock near the surface is completely impregnated with oil.

Between Sour Lake and Houston, 50 m. farther west, many experiments are in progress, but no success has been reported. In the city of Houston, I was informed by Major Cave, of the Houston and Texas Central Railway, that a small flow of oil had come from his well for many years.

Fifty miles S. of Houston, near the mouth of the Brazos river, in Brazoria county, there is a field which, according to Captain Lucas and the geological evidence which we possess, gives excellent indications for oil. There were no less than fourteen expensive well-rigs set up in this and Brazoria county, four of which were upon the remarkable hill known as Damon's Mound, one or two at Big Hill, and one at Keyser's Mound.

The wells on Damon's Mound encountered small flows of oil at depths of from 400 to 600 ft., exactly as at Beaumont;

but so far they have been unsuccessful in securing a commercial flow.

At Keyser's Mound, in the same county, about 6 m. north of Damon's, and near the Brazos river, a flow of oil was struck at about 400 ft.; but unfortunately the drillers were unable to cut off a tremendous flow of artesian water which was encountered just above it; and, as a result, the well produces to-day a remarkable emulsion of oil and water.

The well at Velasco (Bryan Heights) struck, at about 600 ft., a flow of gas so violent that its roar could be heard for miles. As a gas-well, this was as remarkable a phenomenon as were the Spindle Top oil-"gushers." The flow of gas could never be controlled; the well had to be abandoned; and a new hole, started beside the old one, is now giving every indication of securing oil.

Proceeding southward throughout the vast desert of the Lower Rio Grande, small quantities of oil have been encountered at several places, while still farther southward, at the end of our Coastal Plain, some miles from Beaumont, authentic reports have recently been received that flowing wells have been developed at Tampico, Mexico. Even as far south as the State of Tobasco, two flowing wells are reported. These results of a single year, although still fragmentary, are sufficient to reinforce our belief that in the future years the Beaumont field will furnish other profitable localities of commercial oil beside Spindle Top.

A Year's Development.—On January 10, 1902, one year from the date of the discovery of oil, there were 136 wells on Spindle Top. Operations for the first three months of the second year show a great increase; the number of "gushers" has grown from 136 to 214, and more wells are drilling at present than at any previous time.

Three pipe-lines have been finished, two to Port Arthur (19 miles) and one to Sabine (24 miles). Pipe-lines from Beaumont to New Orleans and Beaumont to Galveston, Houston, and other Texas points, are contemplated.

On March 1, the tank-storage exceeded 5,000,000 barrels. Among the tanks of 37,500 bbl. capacity and over were 22 at El Vista, 28 at Gladys, and 33 at Port Arthur.

The demand for tank-cars has constantly increased. In Feb-

ruary, 1902, 500 cars were added, making a total at that time of 1500. The Southern Pacific Railway has since purchased 250 tank-cars of 12,850 gallons capacity each, and many of the cars have already arrived at the loading tracks. Many companies now have ample shipping-facilities. In addition to the regular tank-car lines, there are between 800 and 1000 tank-cars owned by local oil-companies. A huge tank-car factory is being erected at Beaumont to supply the demand.

Tank-steamers also have been in great demand. Many ships have cleared from Port Arthur; but the supply nowhere approximates the demand. The Guffey Co. is constructing five steamers, one of which, to carry 60,000 bbls., is the largest ever made in America, and will equal any in the world.

The Guffey Co. already has two refineries completed at Port Arthur, and another approaching completion. Work on five other refineries is progressing rapidly. Guffey Refinery No. 3, at Port Arthur, will have a capacity of 2500 barrels per day. This company will ship no crude oil, but will bring the flash-point up from 120° to 145° and 150°, by taking out naphtha and kerosene, before shipment.

Within a year from its discovery, Beaumont oil is burning in Germany, England, Cuba, Mexico, New York and Philadelphia. By its energy steamers are being propelled across the ocean, trains are hastening across the continent, electricity generated and artificial ice frozen in New York, ores ground and stamped in Mexico, Portland cement manufactured in Havana and Texas, and gas enriched in Philadelphia; and this, too, while half the world is either unaware or incredulous of the value of this fuel.

A strong demand for the oil comes from the manufacturers of illuminating-gas. In March, this demand from New York and Philadelphia was great enough to justify a daily steamer from Port Arthur to those cities. The oil is also being sent to Atlanta and other cities for this purpose.

Many of the great railway-lines of Texas have changed or prepared to change from coal to oil as fuel for their locomotives. The oil is also being used in hundreds of small factories in Texas, such as breweries, brickyards, etc. Even the farmers are using it as a fuel sufficiently inexpensive to permit of pumping for irrigation.

The production of the Beaumont oil-field during its first year was limited for the lack of means of distribution. It is estimated, however, that 5,500,000 barrels were actually drawn from the great reservoir—one-half of which was stored in tanks and the remainder consumed, shipped or wasted.

The shipments for 1901 were 1,750,000 bbls.; for the first three months of 1902 they exceeded that total, those for March alone being more than 800,000 bbls. The field will probably ship 20,000,000 bbls. in 1902.

It is estimated that the development of this field has cost $7,000,000, of which about $1,250,000 has been paid for labor. The tubing and well-drill rigs have cost, approximately, another million. Pipe-lines, lumber for derricks, and tanks for storing the oil, have consumed the remainder.

The average cost of sinking a well at Spindle Top is $7249. The 215 wells that are "in," together with the adjacent "dusters," have cost fully $2,000,000. Probably $50,000,000 more has been expended for purchases of land, transportation facilities, and other legitimate purposes. The capitalization of the 200 companies in the field is placed at $200,000,000.

Before Capt. Lucas's well came in, land could be purchased anywhere in the Coast Prairie country for less than $4.00 an acre. Millions of acres have since changed hands at fabulous prices, while every foot has been leased for favorable considerations. Thousands of acres of this land 150 miles from Beaumont have sold for as much as $1000 per acre. Land within the proved field has sold for nearly $1,000,000 an acre; $900,000 having recently been paid for one acre. No sales were made for less than $200,000 per acre. Spindle Top today may be justly assessed at a valuation of $500,000 an acre, or $100,000,000. Two years ago it could have been bought for less than $10 an acre.

The 214 wells upon the field are owned by about one hundred companies. It is estimated that 120 of the wells are located upon 15 of the 200 acres of productive territory. These wells are in the hands of nearly as many individual companies, mostly small organizations without means for operation or facilities for outlet and transportation. The remainder of the territory is within the hands of four or five legitimate operators, who not only possess wells, but tank-

cars, pipe-lines, refineries, etc., for handling and marketing the oil.

The Geology of the Beaumont Field.

The Coast Prairie.—This belt of prairie-land, from 10 to 50 miles wide, which borders the Gulf of Mexico for nearly 400 miles from the Mississippi in western Louisiana through Texas into Mexico, is one of the newest made and least understood of our American geographic provinces. It is a grass-covered constructional plain, newly reclaimed from the Gulf of Mexico. In general character it resembles very much the New Jersey flats of our northern coast, with which it has many features of age and mode of origin in common.

Topographically, it is almost level, sloping seaward at the rate of about one foot to the mile; its interior margin rises scarcely 100 ft. above the sea. It is impossible with present knowledge to delineate the interior border with exactness; for belts of timber constantly encroach upon it. Its almost level surface is broken by a few low drainage-grooves. There are deep drowned bayous in Louisiana and east Texas; but these become fewer and more faintly developed toward the Rio Grande.

No topographic surveys have ever been made of any portion of the Coast Prairie, and hence the slight irregularities of its contour are discernible only with difficulty. Until Capt. Lucas's investigations, certain low elevations, which have since become the most important features of the landscape, were hardly noticed. I allude to low swells or hills such as Spindle Top, which occur here and there, and now attract attention from their supposed relation to the occurrence of oil beneath them. These mounds or hills are in reality gentle swells.

Until the past decade this country, which is swampy in places and in its southwestern extension semi-arid, was considered good only for cattle-raising. For fifty years, immigration passed beyond it to the more fertile portions of the State. Prior to the recent oil boom, however, it was acquiring a great impetus through the development of rice-culture, and to-day it is one of the most active industrial sections of the Union.

Geology of the Coast Prairie.—The low relief of the Coast Prairie, the absence of extensive natural or artificial cuttings and the mantle of vegetation render difficult the study of the

problems of its stratigraphy and structure. We know that this prairie is underlaid to an indefinite depth by a series of sea-muds and sands similar to the present marginal deposits of the Gulf. On a previous page I have given the geological series which should underlie the prairie, and called attention to the difficulty of classifying the later beds. These late Tertiary (Neocene) and Pleistocene formations which succeed the Frio clays of Kennedy (the top of the Angelina series), underlie the Coast Prairie, and contain the oil, have never been classified, and may be called the *X* beds until a definite classification is made. In addition to very recent alluvium and loam, they may include the formations described in Louisiana as the "Hudson" and "Grand Gulf." Paleontologists have also identified shells from the Galveston and Beaumont wells, which they referred to the Miocene; but no geologist has ever identified formations of this age outcropping at the surface in the Texas series.

No proof has been obtained of the total thickness of the *X* beds nor the depth of the top of the Eocene Tertiary, beneath the Coast Prairie. In fact not one of the drill-holes in the Coast Prairie, the deepest of which was the well at Galveston, Texas (3050 ft.), has ever penetrated to it. According to the section of this well, there are 2920 ft. of such strata beneath the Texas Coast Prairie of Recent, Pleistocene and Miocene age.

Some sections have been published which convey an idea of the material of the unconsolidated *X* beds. They are composed almost entirely of unconsolidated material, which weathers into a mantle of soil. One section at Beaumont shows the strata down to the oil-bearing rocks. Another, of the deep well at Galveston, Texas, includes the equivalents of all the strata passed through in the Beaumont well, together with 2000 ft. of lower, and probably from 100 to 3000 ft. of higher, beds.

A third section is that of the Louisiana Petroleum and Coal Oil Co.'s well, 1230 ft. deep, in Calcasieu parish, on one of two small islands in the marsh which forms the head of the Bayou Choupique. The section, originally given by Hilgard, is republished in the *Geological Survey Report of Louisiana* for 1899, page 25.

A fourth section is that of the wells at Belle Isle, given in the *Louisiana Geological Survey Report* for 1899, Plate XXII.

Some information concerning the formation of the Coast Prairie, with a *résumé* of previous work, is found in a preliminary report of the geology of Louisiana, transmitted in November, 1899, but without date of publication on the title-page (probably 1900). On the map accompanying this report, it is remarked that the distribution of the post-Eocene deposits is based mainly on previous surveys.

A few fragmentary data concerning the character of the formation have been given by Dr. Loughridge in the special report on cotton production for the Ninth Census; but, as a whole, the Neocene, Pleistocene and Recent formations immediately underlying the Coast Prairie are still unstudied and uncorrelated.

Several of these sections would lead the reader to infer that the bottom of the *X* beds had been reached when the bodies of salt, sulphur and gypsum were encountered, and that these materials are of Cretaceous age. Evidence will be presented later to show that this may not be the case.

According to a special report by Hilgard for the Louisiana Geological Survey, the Five Islands are the erosion-formed outliers of a Cretaceous ridge or backbone which traverses Louisiana from its NW. corner in the direction of Vermilion Bay; and many geologists have referred the salt- and sulphur-beds to the Cretaceous.

A sifting of all the evidence upon the subject affords no proof of the Cretaceous age of the salt islands, which has been asserted solely on lithologic grounds, paleontologic evidence being entirely lacking. It is true that there is a change of material in several of the drill-holes, as, for instance, from the salt of the salt island and Damon's Mound, and the dolomite of Big Hill; but if these materials have originated by secondary replacement, as I maintain may have happened, they may be of post-Tertiary age.

Structure of the Coast Prairie.—The Coast Prairie is topographically monotonous and so near to sea level, and the geological formations so unconsolidated and indeterminate, that there are no surface factors to enable one to determine the elementary features of structural deformation, such as the anticlines and synclines, which are so easily traceable in other regions where indurated rocks abound. Notwithstanding its

apparent simplicity, however, there are some knotty problems in the underground structure of the Coast Prairie, which presents a peculiar exception to all the rest of the Coastal Plain. As already observed, the outcrops of lower and lower beds occur in succession from the coast inward. But this is not true of the *X* beds. There is distinct evidence that, among these, newer beds overlap older formations, which do not outcrop at the surface anywhere in the Coastal Plain. Thus, Miocene fossils have been recognized in the Galveston and Beaumont wells, where no formations of this age are known to outcrop anywhere at the surface. The stratigraphic unconformities noted by Kennedy between the Camden and Angelina series, and the Angelina series and the *X* beds, also have an important bearing on this question.

There is some evidence that the Coast Prairie overlaps conceal a line of serious deformation, which may be a sharp fold, with an increased dip coastward, or a zone of faulting. The normal dip of the Eocene strata immediately W. of the Coastal Plain is from 10 to 20 ft. per mile. If this rate of inclination continued to the coast, these strata would be buried only from 500 to 1000 ft. But, as I have shown, they are probably more than 3000 ft. below the surface, showing either a rapid change in dip to 60 ft. per mile, or a downthrow-fault.

If such faulting or deformation exists beneath the Coast Prairie, overlapped and buried by later surface formations, the fact is most important. I shall recur to it later.

The Louisiana part of the prairie is acknowledged to be a subsiding area, as attested by actual bench-marks, the drowned character of the bayous, and the circle of cypress growth on the swamps. I know of no actual previous observations bearing upon the isostasy of the Texas portion of the prairie. McGee, in a recent article in the *National Geographic Magazine*, assumes that it is likewise subsiding; but observations made within the past year lead me to believe that west of the Trinity river, at least as far south as the mouth of the Colorado—beyond which we know nothing—the plain is rising. Between the Trinity and the Colorado all the streams have new-cut channels, characteristic of rising land, while the Brazos is actually cutting down through its own alluvium at sea-level, and for many miles above its mouth.

In the generally monotonous monoclinal structure there are a few wrinkles or small swells, likely to escape the eye of even the trained observer, and yet of a character which may have an important bearing on the oil-problem. These are the circular and oval mounds already described, which were first recognized by Capt. Lucas. When he pointed out Spindle Top hill to me, my eye could hardly detect it; for it rises by a gradual slope only 10 ft. above the surrounding prairie plains. I was still more incredulous when he insisted that this mound, only 200 acres in extent, was an uplifted dome. But Capt. Lucas said that I would be convinced of the uplift if I could see Damon's Mound in Brazoria county. In August, 1901, I visited that place, and then returned for a second look at Spindle Top, and was convinced that, if these hills are not recent quaquaversal uplifts, no other known hypothesis will explain them.

Damon's Mound is an elliptical hill, a mile or more in greater diameter, rising 90 ft. above the surrounding level. Its profile is everywhere convex, and it is not a hill of erosion or of volcanic material. Furthermore, a bed of limestone follows the contour of its surface, showing deformation. The ascent of the plain will not carry the latter to the height of this mound for 100 m. interior-ward.

Phenomena Accompanying the Oil in the Beaumont Field.—By studies and drill-sections of the Coast Prairie, the following facts have been developed:

1. The oil is closely associated with the mounds, occurring on their slopes or summits.

2. The mounds are usually anticlinal or quaquaversal in structure.

3. Most of the chemical phenomena of the Lucas group occur in all these mounds in varying proportions.

4. In some localities, hot water has been struck below the oil.

5. In the original Lucas well, the oil itself is hot.

The oil seems to occur, not in any definite, continuous stratum, but in spots of many strata, under varying conditions. At several places, notably Rockland, Saratoga and Sour Lake, it is found at the surface as a maltha or asphaltum, impregnating spots in beds of sand, which are indurated by it. At Jennings, Beaumont, Sour Lake, and other localities, several—at

Sour Lake, for instance, eleven—"seeps" of oil have been encountered.

Gas in immense quantities, and frequently under such pressure as to wreck the wells, has been struck before reaching the oil. This has occurred several times at Spindle Top, twice at Sour Lake, and once at Velasco, where the destructive effect was terrific.

Sulphur and sulphuretted hydrogen gas occur in intimate association with the Beaumont oil. In fact, the oil itself is said to contain from 1 to 2 per cent. of sulphur, and the fumes of sulphuretted hydrogen are strong in the vicinity of the wells.

Captain Lucas early noticed that sulphuretted hydrogen, escaping from the earth under certain conditions, deposited sulphur in crevices near the surface. Such phenomena he observed at Spindle Top before commencing his well. At High Island, Galveston county, work was temporarily suspended on a well-hole, and the orifice was stopped with hay, in order to prevent obstruction from *débris*. Afterwards, when this plug was withdrawn, the hay was found to be imbedded in a matrix of sulphur, undoubtedly deposited from the escaping gas. At Damon's Mound, Brazoria county, sulphur was found near the surface only, in small joints and fissures; and a clay impregnated with it, used as an ointment by the Indians who formerly inhabited the coast country, was subsequently mined and sold as a medicine by a company of Americans.

Underground bodies of sulphur, associated with the oil by natural processes, have been found in many localities. The Calcasieu section of Hilgard shows at 540 ft. in depth solid "sulphur rock," similar to that encountered at 1040 ft. in the Beaumont well. At Damon's Mound a bed of sulphur from 10 to 40 ft. thick was encountered above the salt. Crystals of free sulphur also occur in cap-rock overlying the Spindle Top oil.

The following is reported of the well bored by Boughton & Wynn for the Higgins Oil Co. at Spindle Top, about 800 ft. from the Lucas well. I cannot vouch for the correctness of the statement:

"The drillers claim that the oil-pool struck by their well is 40 ft. deep, and that the oil rests upon a bed of sulphur. After the oil was struck, the borers permitted the pipe to sink until it struck bottom, which it did at the distance of 40 ft. The drillers then claim to have bored 4 ft. into a bed of pure sulphur."

The bodies of sulphur are probably a by-product of the formation of the oil, which, at Spindle Top, is not only highly saturated with sulphuretted hydrogen, but contains by chemical analysis from 1.5 to 3 per cent. of sulphur. It was Capt. Lucas who discovered the relation between the sulphuretted hydrogen fumaroles, gas-springs and sulphur incrustations at the surface, and the bodies of subterranean oil; and it was his belief in this association that led him to seek for oil on Spindle Top hill.

The bodies of salt discovered beneath the hills of the Coast Prairie are of remarkable size, thickness and purity,—notably those in Louisiana, and one discovered within the past few months at Damon's Mound, in Brazoria county, Texas.

The salt islands of Louisiana were described by Captain Lucas in the *Transactions* of the American Institute of Mining Engineers before his discovery of oil at Beaumont.* These so-called islands, rising from 80 to 250 ft. above the surrounding marshes of the Coast Prairie, are hills beneath layers of stratified clay and sand. They belong to the same group of topographic phenomena as Spindle Top hill at Beaumont.

By sinking through the superstructure of sand and clay, Capt. Lucas located the salt-bodies and determined their horizontal extent, developing also the important fact that, though limited in diameter, they were of great depth,—that of Jefferson Island having been penetrated for 2100 ft. without reaching bottom.

Another important fact pointed out in Capt. Lucas's paper was that the substrata of the southeastern part of Belle Isle, above and down to the rock-salt, were heavily impregnated with petroleum. Several calcareous strata containing sulphur were also encountered, suggesting to him that more thorough exploration might develop a sulphur-deposit like the great Calcasieu deposit, and showing the association of these three materials.

All geologists who have expressed an opinion have committed themselves to the theory that these salt-masses were originally deposited in the sea and covered with later sediments. Capt. Lucas also accepted this hypothesis. The theory as stated by Adams† was that, "near the close of the Cretaceous period, beds of rock-salt and gypsum were evidently precipitated in the land-locked remnants of the retreating sea."

* *Trans.*, xxix., 462 *et seq.* † *U. S. Geol. Sur.*, *Bulletin* No. 184, p. 49.

The sediments of the lagoons which in former times, as today, bordered the Gulf of Mexico, were undoubtedly very saline; but we have no instances at present to lead us to suspect or believe that there have ever been conditions for the accumulation, by surface evaporation in such lagoons, of the enormous thickness of salt now found beneath the Coast Prairie mounds of Louisiana and Texas.

These vast salt-bodies are intimate historic associates of the oil, and record the past location of the circulation of saline waters, which were transporting agents in the distribution of the oil.

Since studying the phenomena of the Beaumont field, the writer has gradually developed another hypothesis, namely, that these salt bodies are the result of secondary replacement in the strata through the agency of the ascending circulation of saturated briny waters, as elsewhere explained.

Still another interesting phenomenon is the occurrence of dolomite. The oil of Spindle Top is said to occur in a cavernous mass of this material. At Big Hill, Jefferson county, which is one of the most conspicuous of the mounds, the drill, after going down 300 ft., penetrated a mass of solid, coarsely crystalline dolomite, in which it continued to nearly 1375 ft. At 900 ft. a small seep of oil was struck in the dolomite. This would suggest, at first glance, that a boss of ancient crystalline rock had been encountered; but such is probably not the case, as I shall endeavor to show.

In only one well, so far as I am able to ascertain, has the hot salt water been encountered, which would be expected to follow the oil. This was in the Sour Lake field, where, as I am informed by the owner, a heavy flow of hot salt water was struck at about 1400 ft.—a lower level than that of the "gusher"-oil of that vicinity.

The fact that the oil in the original Lucas gusher had a temperature of over 110° F. is most important. This phenomenon seems to have been overlooked heretofore by those who have studied the field.

Explorations have shown the following downward series in the quaquaversal hills: (1) a matrix or overlay of the typical Coast Prairie formations; (2) oil-phenomena, consisting of sulphuretted hydrogen gas, escaping superficially, and secon-

dary deposits of sulphur in the strata through which the sulphuretted gas has ascended; (3) oil, mixed with considerable sulphur and sulphuretted hydrogen; (4) sulphur, as a precipitate or sediment of the oil; (5) sodium chloride and magnesian lime carbonate, as after-products of the oil; and (6) hot salt water, under great hydrostatic pressure.

Geological Source and Distribution of the Oil.

The ablest geological experts and practical oil-men have found the conditions in the Beaumont field different in every detail from those of all previously discovered fields, especially those of Ohio, California, West Virginia and Pennsylvania. The magnificent work of Orton in Ohio, White in Virginia, and Lesley and others in Pennsylvania, is inapplicable in this field.

The writer, like other geologists, assumed at first that the oil-deposit was more or less of the sheet or blanket type, and for a while proceeded upon that theory, until it was upset by experiments around Spindle Top. A year ago I was inclined to believe that the Beaumont oil was, like that of the Trenton, Berea and Corsicana fields, indigenous to certain strata. But we are unable to define and describe such strata; and all evidence now tends to disprove that proposition.

While science has said, frankly, "We do not know, but we shall learn," fakirs of every imaginable kind and well-meaning practitioners from other fields have given advice in abundance. The man with the divining-switch; the boy who could see underground streams blindfold in the night; the electrical-indicator man; the Pennsylvania oil-driller who recognized Pleistocene and Recent gravels on the surface as identical with the Paleozoic conglomerates of his native State; and a host of quack-geologists, have reaped a rich harvest in this field through the foolish and fruitless expenditure of much money.

Before the discovery at Spindle Top, there was only one man whose ideas, although not yet co-ordinated into a theory, approximately fitted the observed conditions. Of course I refer to Capt. Lucas, who, in his explorations of the Coastal Plain, seeking successively salt, sulphur and oil, had observed the association of oil, sulphur, sulphuretted hydrogen gas, gypsum, dolomite and salt, constituting collectively what might be termed

the oil-phenomena, representing a group of secondary products, as distinguished from the mother-strata or sediments out of which they had been produced. Moreover, so far as I am aware, he first pointed out the existence of anticlinal hills in the Coast Prairie, and their connection with the oil-phenomena. Concerning the origin and geology of the oil, however, he presented no opinions.

Capt. Lucas also attached much significance to certain surface-phenomena, indicating that the sulphuretted hydrogen, escaping upward, either acidulated the surface-waters or deposited incrustations of sulphur in the soil. He inclined to believe that the mounds themselves were in some manner the result of the gas-pressure; and I think he favored the notion of horizontal distribution along lines of strike.

An Explanatory Hypothesis.

The writer has in mind a hypothesis, not hitherto advanced, so far as he is aware, which co-ordinates Capt. Lucas' data and explains that which he omitted, the source and distribution of the oil, salt-islands, sulphur, sulphuretted hydrogen gas, and dolomite. This hypothesis is offered with hesitation, not as a final explanation, but in the hope that it may serve as a basis for discussion, through which the truth may be reached. I think it fully interprets the Lucas group of phenomena, and accounts for the mystery of Spindle Top far more satisfactorily than any other thus far presented, and that it may also account for the independent origin of the sulphur, sulphuretted hydrogen and gypsum, regardless of their association with the oil.

This hypothesis is as follows: *The oil- and salt-pockets of the Texas Coastal Plain are probably not indigenous to the strata in which they are found, but are the resultant products of columns of hot saline waters which have ascended, under hydrostatic pressure, at points along lines of structural weakness, through thousands of feet of shale, sand, and marine littoral sediments of the Coastal Plain section, through which oil and sand are disseminated in more or less minute quantities. The oil, with sulphur, may have been floated upward on these waters, and the salt and dolomite may have been crystallized from the saturated solution.*

The channels of these ascending waters may have been in places of structural weakness, such as fissures, which probably at one time con-

tinued to the surface, but may have been sealed by the deposition of the later overlapping strata now capping the oil-pools. Such features, when occurring under gentle anticlines, may explain the collection of oil beneath the surface in pools.

The following known data may be adduced in support of this hypothesis: (1) The absence, at the depth of the Beaumont wells, of any local sheet or stratum from which it is probable that the tremendous body of oil could have been generated; (2) the probable existence of nearly 10,000 ft. of Cretaceous, Tertiary, Quaternary and Recent unconsolidated sediments beneath the surface of the Coastal Plain, as demonstrated by the deep well at Galveston, and studies of the outcrops farther inland: (3) the dip of these strata beneath the Coast Prairie at a low angle, from the interior coastward; (4) the oil disseminated in small quantities in many of these strata; (5) the existence of seven or eight distinct reservoirs of artesian water in this series of strata, at depths which increase coastward; (6) the fact, demonstrated by artesian wells, that the water becomes hotter and more saline with increasing depth, thereby increasing its capacity for the collection and flotation of oil; (7) the intense hydrostatic pressure in these water-bearing strata, which apparently continue beneath the Coastal Plain; (8) the fact that this water has risen in spots along lines of fissure which are probably later, and are capped by 1000 ft. or more of the still later strata of the Coastal Prairie.

The evidence of these statements is as follows:

1. Experiments at Spindle Top, Saratoga, Jennings, Sour Lake and Velasco show that the accumulations of oil sufficient to produce gushers are not indigenous to the particular stratum in which they are found, but have been collected there as a result of other causes. It is also certain that the oil occurs in underground pools, which are related to the supposed anticlinal mounds in the new-made Recent Coast Prairie.

The main supply of oil at Spindle Top averages 1000 ft. in depth, and may be in strata of Pliocene or allied Miocene age. But that this stratum in which the oil occurs is not continuously impregnated as a widespread sheet is testified by the barren ground developed all around Spindle Top. Nor do the many drill-holes bored up to this date reveal any formation in the upper portion of the Coastal Plain capable of generating

the vast quantity of oil found at Spindle Top, whatever its origin. These oils are not associated with extensive beds of either plant or animal remains from which the oil might have been generated. At one place, Saratoga, where they outcrop, they apparently occur in ferruginous sands.

A faint trace of oil is usually encountered at from 400 to 600 ft. in depth, throughout the entire three hundred miles from Damon's Mound to Jennings. This was probably the first "seep" oil struck at about 600 or 700 ft. in the Lucas well, and has been encountered at many other places. It may be a local horizon; but it has not been found to be always underlaid by a great "gusher" stratum, or by any signs of such a thing. That there are shallow strata beneath the Coastal Plain which are oil-bearing is apparent; but the product of all of these put together would not supply one "gusher."

2. The now classical section of the deep well at Galveston, only a short distance from Beaumont, shows that there are at least 3000 ft. of unconsolidated Gulf littoral sediments, of later age than the Eocene Tertiary.

Beneath this, there is every reason to believe (from its outcrop to the westward and dip toward the Gulf Prairie) that there must be an additional 300 ft. of Eocene Tertiary sands and clays. Similarly, west of the Tertiary, and dipping beneath it, geologists have measured at least 4000 ft. of marine Cretaceous formations, also dipping directly beneath the Coastal Plain.

If all these strata do (and no evidence has been as yet presented to show that they do not) extend beneath the Coast Prairie, then we have beneath it at least 10,000 ft. of Cretaceous and later sediments, known to be (with the exception of 1000 ft. of consolidated limestones) almost entirely composed of more or less littoral, terrigenous, bituminous and ferruginous clay and sand.

3. The dip of the buried portion of the strata of the Cretaceous and Eocene series beneath the present coast prairie is evident from the minute studies of the outcrops of these strata towards the interior. The Cretaceous strata dip toward the Coast Prairie from 25 to 40 ft. per mile, as shown with great minuteness in the author's monograph of the Cretaceous formations.* The dips of the Eocene Tertiary, from 30 to 10 ft. per

* 21st *Ann. Rep. U. S. Geol. Surv.*, Part VII.

mile, are given in the various reports of the Texas Surveys. While no one can say positively that these strata are beneath the Coast Prairie, induction leads to no other conclusion, and absolutely no reason can be advanced to prove that they are not.

4. Of the 22,000 ft. of sedimentaries in the Texas section, all but less than 2000 ft. are unconsolidated clays and sands, which may be more or less bituminous. Some of the limestones are also bituminous. Oil or bitumen has been found in at least a dozen horizons of the section. The older or Paleozoic group contains one in the Ordovician, and two or three in the Carboniferous (as at Brownwood, and at Henrietta, in Indian Territory). Of the strata comprising the later grand group underlying the Coastal Plain, there are five oil horizons in the Cretaceous: one in the base of the lower Cretaceous (at St. Jo and Burnet); one in the Del Rio clays at Austin; one in the Eagle Ford clays in Grayson county; two in the Navarro beds of Corsicana; several in the Eocene—notably that at Nacogdoches—and several in the post-Eocene at Beaumont.

In two instances, in Texas, bituminous matter (asphaltum) is found in apparently indigenous beds of lime-shell conglomerate. One of these is the shell-breccia bed of the Travis Peak formation at Port Mountain, in Burnet county; the other is the shell-breccia in the upper Cretaceous at Cline, from which the Uvalde asphaltum is obtained.

The oil of the Corsicana field and that of San Antonio is derived from the shales of the Upper Cretaceous. The same strata which produce oil at Corsicana would, if continued, probably be embedded at least 4000 or 5000 ft. beneath Beaumont.

The strata of the Eocene Tertiary present every favorable condition for the generation of petroleum, whether this material be derived from the decomposition of marine organisms, as alleged by some, or from the hydro-carbons generated by vegetable matter, as believed by others. There are vast accumulations of both materials in eastern Texas.

It is an interesting fact that asphalts and oils rich in asphaltum occur in terrigenous (land-derived) sediments of the nature, age and general character of the East Texas Eocene,

around the entire perimeter of the Gulf of Mexico and the Caribbean Sea. The asphalts of Tamaulipas in Mexico, Vera Cruz, the Isthmus of Panama and Cuba, as well as the great asphalt-deposits of Trinidad, Barbados and Venezuela, all come from beds of this character.

The oil from the Nacogdoches well is derived from near the top of the lignitic formations (Claiborne beds) of the Eocene Tertiary, the position of which has been definitely ascertained by geological study.

The *X* beds (post-Eocene) of the Coast Prairie are apparently rich in oily spots.

If a drill-hole could be continued to a depth of 10,000 ft. below Beaumont, it should encounter: first, the Nacogdoches oil-stratum; next, the bituminous shales of the Eocene; next, the oil-shales of the Corsicana field; next, the Eagle Ford (Colorado) bituminous shales; then the bituminous beds which furnish the asphaltum of St. Jo and Burnet; and, finally, the oil-shales of the Carboniferous. None of these strata were encountered within 3000 ft. of the surface in the deep wells at Galveston, or in any of the wells of the Coastal Plain. Between the Eocene or Claiborne stratum of Nacogdoches and the uppermost Pleistocene stratum of Beaumont there are thousands of feet of gypsiferous clays and sands in which nature may now be distilling oil.

5. That the strata dipping beneath the Coast Prairie contain many beds (reservoirs) of artesian water is proved by extensive records and observations. These horizons are fully described in the writer's paper on the "Artesian Waters of Black and Grand Prairies.*

6. This water increases in temperature with depth, and in its capacity for taking in solution the solvent salts and for upward flotation of the oil gathered in particles from the various strata through which it passes in greatest quantity. The fact that the water increases in temperature and salinity is conclusively proved by a line of wells, 100 m. in length, between Comanche and Marlin, in the lower portion of the Cretaceous series. The

* 21*st Ann. Rep. U. S. Geol. Surv.*, Part VII., p. 387, Washington, D. C., 1902.

same stratum which furnishes water at both places outcrops at Comanche and supplies good potable water at almost every atmospheric temperature. At Marlin, 100 m. eastward, this water comes from a depth of 3200 ft., has a temperature of nearly 140° F., and is excessively saline and sulphurous. Should the rate continue from Marlin to Galveston, this stratum would be, at the latter place, nearly 1000 ft. below the surface, and intensely heated and saline.

7. If the lowest water-sands of the Cretaceous of Texas are embedded beneath the Coastal Plain, several thousand feet below their outcrop, they must be under tremendous hydrostatic pressure. Their water must ever pass upward, and would take advantage of any structural weakness in the overlying beds to do so.

8. In the discussion of the geology of the Coast Prairie, I have given some evidence of the existence of a strong monoclinal fold or faulting beneath the Coast Prairie.

There is much evidence that the present and former Coastal Plains of Texas, marking the recedence of the old shore-line of the Gulf of Mexico from the Rocky Mountain region to its present site, has experienced periods of pause, producing a series of concentric shore-lines, accompanied by faulting. It is a singular fact that in another part of Texas, adjacent to a region which was at one time a coast-line of the Gulf of Mexico, there existed such a line of weakness. The great Balcones fault, which the writer has frequently described, is of this character. It is very probable that, along the present coast-line, similar faulting took place in Neocene time, and that the evidence thereof has been obscured by overlapping of the Grand Gulf and later formations, which veil the Coast Prairie.

It is also true that there are unconformities in the coastal section, such as the one described by Kennedy, which might have overlaid such fault-fissures in the Coast Prairie with more recent deposits.

If these deeply embedded water-bearing strata under tremendous hydrostatic head exist beneath the Coast Prairie, their waters would pass through any natural channels, such as fault-fissures, through all of the known sheet-oil horizons of Texas, except those of the Carboniferous formation. Such

hot water would gather from the rocks, which are known to contain them, oil, salt, lime, sulphur and gypsum; and the oil gathered from these strata would be floated on the ascending saline waters.

If ascending columns of oil and water of this character should meet resistance near the surface, we could well conceive of the formation of such a pool as that beneath Spindle Top hill. To produce such a formation, which would be practically like the end of a "mushroom" bullet, there must be resistance; and this resistance would naturally come from an impervious formation. The overlap of the upper *X* beds of the Coast Prairie, stopping the free exit of the water upward through the fault-lines, would produce such a resistance; and this overlap we believe to have taken place.

At any rate, should such a column of ascending water, with oil on top of it, reach a resistance near the surface, a subterranean pool of oil would result, such as we find at Spindle Top. Furthermore, the reaction which would take place in the column of water below the oil could theoretically account for all of the after-phenomena of the Coast Prairie mounds, such as the salt-islands of Louisiana and Damon's Mound, and the dolomite of Big Hill.

It is a remarkably interesting fact that in the mammoth artesian springs of the Balcones fault-zone, between Austin and Del Rio, we have an analogous group of data, showing the rise of subterranean water in spots along a line of faulting. Along this line great columns of water are now rising, not continuously, but in spots, like the supposed ancient artesian springs of the Coast Prairie. I allude to the series of springs at Austin, San Marcos, New Braunfels, San Antonio, Fort Clark and Del Rio.*

It is true that these waters do not bring any perceptible oil to the surface; but this is easily explained, since they pass mostly through limestones and non-bituminous strata. On the other hand, had they been, as the old structure of the Coast Prairie has been, overlapped by more recent formations, they

* See "Geology of the Edwards Plateau, with Reference to the Occurrence of Underground Waters," *18th Ann. Rep. U. S. Geol. Surv.*, Part II., p 193.

would constitute columns of suppressed water like those we have theoretically supposed beneath the Coast Prairie.

A remarkable discovery has been made within the past few weeks, indicating the correctness, from a scientific point of view, of Capt. Lucas's theory that the mounds were the *loci* of his groups of oil-phenomena, and supporting the hypothesis of ascending waters. In Brazoria county, Texas, some 350 m. west of Belle Island, Louisiana (almost as far as Philadelphia from Cleveland), the lonely mound known as Damon's Mound, similar to those of the Louisiana salt-islands, rises out of the prairie. This has been penetrated, and proved to be an anticlinal dome similar to that of Belle Isle, with a similar stratigraphic section: Pleistocene sand and clay, with traces of sulphur in the surface-layers; oil; then sulphur; and, for its lower 700 ft., pure rock-salt, with occasional traces of oil, demonstrating the occurrence of the latter substance, but not in commercial quantities.

Now the question arises, is Damon's Mound a fossil-oil hill, beneath which the oil once existed but has passed away? If so, why not also the Five Islands, and other salt-islands of Louisiana?

Postscript.

(February 14, 1903.)

Since the above paper was written, nearly a year ago, many events have taken place in the Beaumont oil-field. Jennings, Louisiana, and Sour Lake and Saratoga, Texas, have become productive fields. Oil is also reported in commercial quantities from several other localities. The wells of Spindle Top Hill, on the other hand, have mostly ceased to flow and are now pumped, a result which was naturally to have been expected from the drilling of nearly three hundred (300) wells within a limited space of 150 acres. All in all, the development of the field has been satisfactory; and it is safe to say that the Beaumont oil-field, as a whole, notwithstanding the hundreds of experimental failures, has developed as rapidly as any other field ever discovered, and it is reasonable to expect that new localities will be found as years roll by.

The use of the crude oil has steadily increased until this ma-

terial, which, at the time of its discovery, was pronounced to be unfit for any purpose, is now refined, and sells for as high as 60 to 70 cents a barrel. All of the railways of Texas are using oil, and the Southern Pacific Railway has recently purchased the entire Saratoga fields, and runs its engines from the Atlantic to the Pacific with the Texas material. The legitimate investors have made money and the honest companies are paying dividends. The field has subsided from the condition of frenzied excitement and "wildcat" speculation which marked the first days of its discovery, and has settled down to one of systematic business organization and production. Pipe-lines, refineries and tank-cars are now in great abundance. The statistics are not available for the production of the whole field, but the following, taken from the *Engineering and Mining Journal* for February 7, 1903 (p. 239), shows the production of Spindle Top Hill for 1902:

"*Beaumont Oil-Production in* 1902.—Shipments, January 1 to June 30, 3,768,000 bbls.; July, 850,000; August, 915,000; September, 828,815; October, 916,979; November, 844,791; December, 1,004,569; total shipments, 1902, 9,128,154 bbls.; local consumption, 500,000 bbls.; waste, 1902, 400,000 bbls. Increased oil in store over December 31, 6,105,000 bbls.; total production, 1902, 16,133,154 bbls.

"Total production, 1901, 4,190,000 bbls.

"Total production of field, 20,323,154 bbls.

"Iron tankage completed, 7,280,000 bbls.; earthen reservoirs completed, 7,100,000 bbls.; total tankage, 14,380,000 bbls.

"Oil in store December 31, 1902, 7,105,000 bbls; prices for crude in 1902 varied from 2 to 50 cents a bbl. in tanks."

The Gold-Field of the State of Minas Geraes, Brazil.

BY HERBERT KILBURN SCOTT, LONDON, ENGLAND.

(New York and Philadelphia Meeting, February and May, 1902.)

THE information in this paper was collected by the author during a five years' residence in the State of Minas Geraes. Outside the State itself, very little is known of the gold-field. Such accounts as have been published are antiquated and contained in publications mostly out of print. The increased attention now attracted to the natural resources of Brazil, and the probability that American capital will be, in the near future, largely invested there, will make an up-to-date account specially useful at this time.

I. HISTORICAL AND GENERAL.

Soon after the Jesuits founded what is to-day the city of São Paulo, gold was discovered in the streams of the neighborhood; and this incited the natives, known as *paulistas*, to look for it farther afield. After many expeditions into the interior, gold was found in quantity in placer-deposits in the vicinity of Ouro Preto, in 1699, by a prospecting party headed by Antonio Dias. The name of Ouro Preto (black gold) was given because of the superficial dark coating of the gold, and the inhabitants of the district were known as *mineiros* (miners). Later on, the placers of Cuiaba, in the State of Matto Grosso, were discovered in 1718, and those of the State of Goyaz in 1724. All this territory was at the time a private colony, but on account of its increasing importance it was taken over by the Crown, and in 1739 a royal governor was appointed, with his nominal capital in São Paulo, though for a number of years the real capital was Ouro Preto. In 1711 Ouro Preto was raised to the rank of a city, with the name of Villa Rica de Ouro Preto ("rich city of black gold"); and in 1720, by reason of administrative difficulties, Minas Geraes was constituted a separate colony from São Paulo, with Villa Rica as its capital. The site of this city

was decided by the position of the gold-workings on the precipitous sides of a mountain. (Fig. 10.) The wish to explore, and frequent quarrels amongst themselves, caused many miners to "take to the woods;" and in this way gold was discovered at Marianna, Sabara, Caethe, etc., and in 1720 at Itabira do Matto Dentro. Owing to its virgin forests, the country was at first almost impassable; but in time it became thickly populated and most prosperous, as is proved by the extensive remains of abandoned mining villages.

The Portuguese Government and the Mines.—The Crown of Portugal considered the mineral products of the country its property by royal right, and in 1700 a decree was promulgated to regulate the division of the lands and impose taxes. The auriferous ground was divided into *datas*, or claims, measuring 80 by 40 Portuguese yards, and assigned as follows: one data to the discoverer; one to the Crown; and one to the mine Governor—the rest being distributed by lot. That of the Crown was sometimes sold to the highest bidder and sometimes worked for Government account. The tax, known as the *quinto* (20 per cent. of the value of the gold), was always a fruitful source of trouble between the miners and the Government, since, aside from the large percentage, it was collected in a very arbitrary manner by the Portuguese authorities from the owners and miners, who were generally *paulistas* or *mineiros*. (Figs. 2 and 3.) According to official figures, the total amount of gold received by the Government on account of this tax was 7131 *arrobas*, or nearly 107 tons, equal to about £13,000,000 sterling (*arroba* = 15 kilos). The epoch of greatest prosperity was between 1751 and 1781, when the tax amounted to 100 *arrobas* or 1500 kilos of gold per year.

In 1810, Baron von Eschwege, a Prussian military engineer, was engaged by the Government to examine into the state of the mining industry and initiate modern methods of mining, and it is in his reports that the most reliable information of early mining operations is found. Unfortunately, the natives were opposed to systematic improvements; but he managed to induce the Government to make laws permitting the formation of national and foreign mining companies. In 1817 he commenced work at the Passagem mine, near Marianna, erecting the first gold-milling stamps employed in Brazil. On the

declaration of the independence of Brazil, in 1822, he returned to Europe, and wrote extensively of his travels, the mines, and the geological features of the district.

II. Situation of the Deposits.

The auriferous zone is situated in great part on the Serra do Espinhaço, which crosses the central part of Minas Geraes, and constitutes the watershed between the rivers Doçe and São Francisco. The limits of the gold-field are Sta. Luzia on the north, Brumado on the south, Ponte Nova on the east and Paraopeba on the west. (Fig. 1.)

The diamantiferous region is situated farther north, but is also in part on the Serra do Espinhaço. The district is served by the Central railway of Brazil, an excellent line of more than 1000 kilom., operated by the Government. The gauge is wide (1.6 m., = 5.25 ft.) as far as Lafayette, 463 kilom. from Rio; but from this point onwards it is only 1 m., on account of the mountainous character of the country. The principal mines are east of the railway, and in no case more than 12 kilom. from it. The height of the country varies in altitude between 1000 and 1700 m. above tide, the two highest points being Piedade (1620 m.) and Itacolumi (1713 m.). The climate is healthy, the temperature ranging between the extremes of 35° and 8° C. The average rainfall is about 200 centim. per year, the greater part of which falls during January and February; the rainy season being from October to April, and the dry season from June to September.

III. Geological Features.

With our present geological knowledge it is somewhat difficult to determine the age of the rocks of the district, though it is certain they are very old—according to Dr. Derby, of the Cambrian or Lower Silurian age. (Figs. 4, 5, 6.)

The order of the rocks as seen in the Ouro Preto district is as follows: (1) gneisses and granites; (2) micaceous and talcose schists; (3) schistose quartzites; (4) argillaceous schists; (5) itabirites with *jacutinga* (sandy micaceous iron-ore); (6) limestones; (7) upper micaceous schists.

1. *Gneisses and Granites.*—These rocks appear in immense thickness at the base of nearly all the mountains of the aurif-

erous zone, such as Ouro Preto, Gongo Socco, Caraça, Cocaes, etc. They are often found in an advanced state of decomposition, but rise to a considerable height at times—never, however, forming the highest peaks. Sometimes they are auriferous, as, for instance, at the Candongo gold-mines,* where grains of gold were found in the granitic mass. At other places gold has also been found in the ferruginous granites.

Dr. Derby, in his notes on Brazilian gold-ores, presented to this Institute, notices some auriferous gneiss found in the district, and carefully examined by him.

2. *The Micaceous and Talcose Schists.*—These vary greatly in thickness and composition, partaking of the nature of the rock beneath, and becoming micaceous or talcose, and containing mica or talc in quantity. Though in themselves not auriferous, they are often traversed by quartz-veins of varying thickness, carrying gold. These rocks are generally decomposed to a great depth, and give rise to irregular ravines all over the district, known as *sbarancados.* The predominant type of mica in these rocks is a finely-divided sericite, giving an unctuous aspect that has led to their reference, by most of the travelers who have visited the region, to the talcose group of rocks. True talcose schists certainly occur, but not nearly so prominently as has been supposed.

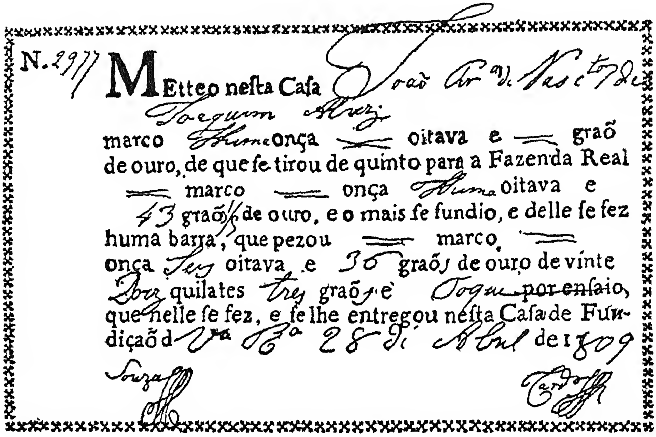
3. *The Schistose Quartzites.*—These are composed of quartz and mica, being very resistant, and with their planes of stratification well defined. They are often used for building purposes, taking the name of *pedra dos lages* (flagstones). At Ouro Preto they are much traversed by quartz-veins, which are auriferous, and especially so at the contact with the enclosing rock. The quartz-lode of the Catta Branca gold-mine crosses these quartzites.

4. *The Argillaceous Schists.*—These vary greatly in thickness, and sometimes almost disappear. In the vicinity of Ouro Preto the early miners drove through them in exploring the quartz-bodies between the quartzites and the itabirites. In some places these schists become chloritic in character, and enclose large quantities of quartz, which is generally auriferous.

* Described in Henwood's *Metalliferous Deposits*, pp. 175, 320. Also, *Trans. Roy. Soc. Cornwall*, vol. viii.

5. *The Itabirites with Jacutinga* consist of quartz (generally disintegrated) and micaceous iron-ore, in layers varying between 1 and 8 centim. in thickness, with the accessory min-

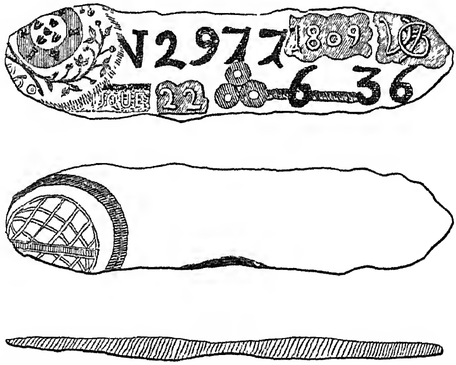
FIG. 2.


N.2977 Metteo neſta Caſa João Pr. de Nas.to de Joaquim Alvez
marco Huma onça — oitava e — graõ
de ouro, de que ſe tirou de quinto para a Fazenda Real
— marco — onça Huma oitava e
43 graõs de ouro, e o mais ſe fundio, e delle ſe fez
huma barra, que pezou — marco —
onça Seis oitava e 36 graõs de ouro de vinte
Dois quilates tres graõs e Joqueu por enſaio,
que nelle ſe fez, e ſe lhe entregou neſta Caſa de Fundição de V.a R.a 28 de Abril de 1809
Souza Cardoso

Melting-House Certificate.

[TRANSLATION: Joas Pereira de Nascimento de Joaquin Alvez has handed into this house one ounce of gold dust, which after deducting the government tax of one-fifth, = one oitava and forty-three grains, has been cast into a bar, which weighs 6 oitavas 36 grains of gold of 22 carats 3 grains fineness, verified by assay, and given to him in this melting house of Villa Rica on the 28th of April, 1809.
SOUZA. CORDOZA.]

FIG. 3.



Bar of Gold Cast in Ouro Preto in 1809. Natural Size.

erals, manganese-ore, scaly talc and iron-glance, in varying proportions. Sometimes, in this rock, the quartz is replaced entirely by oxide of iron, forming a very pure iron-ore, named

locally *pedra de ferro* (ironstone). The thickness of these rocks varies between 20 and 100 m., their outcrops, as well as parts of the surrounding surface, being often covered by a crust of iron-ore conglomerate between 2 and 10 m. in thickness, called *canga.* This iron formation has been proved to be slightly auriferous in many places, but the gold has only been found in payable quantities in the bands of sandy micaceous iron-ore known as *jacutinga.* This gold-bearing formation consists of sandy micaceous and hydrated iron-ore, associated with some yellowish talc and an earthy oxide of manganese, the whole having an unctuous touch, and running conformably to the enclosing itabiritic rock, in lines between 2 and 20 centim. thick. Though not easily distinguished from the enclosing rock by those unacquainted with the formation, the miners recognize it without difficulty. *Jacutinga* gold is usually of high fineness. The mines of Gongo Socco and Maquiné are the two most important which have been worked in this formation.

6. *The Limestones.*—These rocks are generally found immediately above the iron-formation, as at Ouro Preto, Gongo Socco, etc. They are usually dolomitic in character and highly siliceous, owing to the inclusion of material from the adjoining micaceous schists. There is no record that they have at any time been found auriferous.

7. *The Upper Micaceous Schists.*—These strata are immensely thick, and in many places are traversed by a network of small quartz-veins. They are very often auriferous, and were worked on a large scale in the early history of mining in the State. Sometimes the thin veins give place to more important bodies of auriferous ore, consisting of quartz, with large quantities of limonite.

IV. Occurrence of Gold.

The gold occurs either in alluvial deposits or in lodes. The early miners divided the alluvial deposits into three classes: *veias*, or river-washings; *taboleiros*, or lower bench-deposits; and *grupiaras*, or higher bench-deposits.

Of the alluvial deposits, only the beds of the more important rivers remain intact. The bench-deposits were worked out by the early miners; and the rough rubble which covered the auriferous gravel can be seen in huge piles along the slopes of the mountains and sides of the streams.

The lodes may be classified as contact-lodes; lodes in the schists; lodes in the quartzites; lines of *jacutinga* in itabirite.

a. Contact-Lodes.—These are situated along the Ouro Preto mountain range, stretching from about 2 kilom. W. of that city to 4 kilom. on the NE. side of Marianna; and in them the early workers probably did their first lode-mining. The most important mines now working on these lodes are the Passagem and Morro Santa Anna; but Vellosa, Peluçias, Tassara, etc., near the city of Ouro Preto, enjoyed in other times a certain amount of prosperity. The lodes consist of lenticular shoots of quartz,* varying in thickness from 1 to 15, and in length from 10 to 100 m., and interstratified between the itabirites and the underlying quartzites, from which, in some places, they are separated by the argillaceous schist. The shoots are much longer along the dip than on the strike, which necessitates, in mining, some unprofitable driving of levels through the hard quartzites. Some parts of the lode are richer than others, the contents varying between 2 and 200 grammes of gold per ton. This last figure is only attained when the gold is associated with a large quantity of arsenical pyrites. The average gold contents in working the whole of the lode vary very little, the results of the working of the Passagem mine not showing more than 10 per cent. difference in the assay value from year to year. The gold is sometimes visible in the oxidized ore of the old workings near Ouro Preto. At the Passagem mine the shoots are often divided along the strike by horses of the argillaceous schist, easily mistaken for the foot-wall.

b. Lodes in the Schists.—These include by far the greater number of the known mines. They consist of lenticular shoots of quartz varying in size between the large body of the Morro Velho mine, and thin lines in many places alternating with layers of the country-rock. They follow the stratification of the enclosing rock; and the quartz is often associated with ordinary arsenical and magnetic pyrites, as well as limonite, and at some places, like Morro Velho, with the carbonates of lime and magnesia and iron. Sometimes large quantities of visible gold are found in the smaller lodes, though generally these rich

* Dr. Hussak found, on examining the Passagem lode, that it contained patches of kaolinized feldspar; and Dr. Derby has confirmed this, concluding that it is essentially a granitic apophysis.

zones are not very extensive. As far as can be seen, the gold contents of the lodes are constant in depth. That of Morro Velho, for example, has been worked to a depth, on the dip, of about 1700 m. without showing any appreciable difference in size or gold-value.

c. Lodes in the Quartzites.—These are not very important, and at present no mine is in operation upon them. The Catta Branca mine was on a quartzite lode; but no work has been done there for the last 50 years.

d. The Jacutinga Lines in Itabirites.—These are generally not more than a few centimeters in width; and what gold occurs in them is always coarse. In the once famous mine of Gongo Socco, and in others of minor importance, laminated masses of *jacutinga* and gold have been found, weighing many pounds. The huge ravines existing along the mountain-side between Ouro Preto and Marianna are presumed to be the result of the ancient mining of auriferous *jacutinga* in the itabirite.

V. Early Methods of Work.

When gold was first discovered, the *batea* or washing-pan was almost exclusively used; but later the auriferous gravel in the stream-beds was recovered by the erection of coffer-dams at the sides and in the deeper parts, by the use of a small hand-drag. In view of the periodical heavy rains, it is probable that these methods were not very successful.

The lower bench-deposits were worked by *cattas* (rounded pits) dug into the gravel, with sides sufficiently sloped to prevent slips. The miner generally began by sinking a small test-pit; and, if this gave satisfactory results, the hole was widened out, the gravel being piled up around it. To give some idea of the importance of this work, it may be mentioned that in some places *cattas* were dug to the depth of 10 to 15 m. If possible, water was brought by flume to these bench-deposits, as it facilitated greatly the uncovering of the auriferous gravel. The higher bench-deposits naturally required for this purpose the construction of very long flumes (sometimes more than 20 kilom.). In breaking down the gravel by water-power, the gold was roughly concentrated at the foot of the hill by a series of sluices, or by large *mondeos* or settling-pits, some of which may still be found in good repair. All these works were necessarily sus-

pended during the rainy season; and it was the custom to clean up the concentrates when more extensive operations were prevented by the weather.

When the placers had been almost worked out, attention was

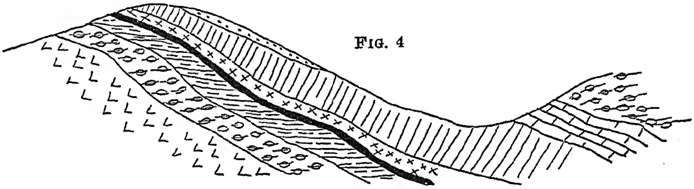


FIG. 4

Section through Ouro Preto Mountain

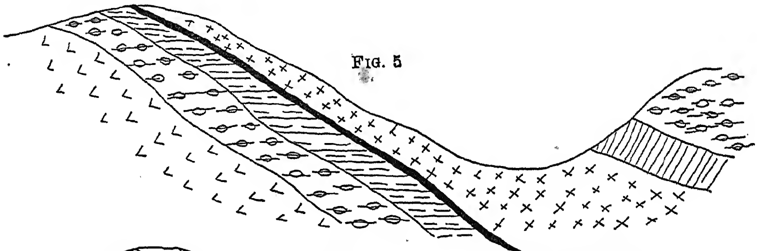


FIG. 5

Section through the Morro Sta. Anna and Maquiné Mountains

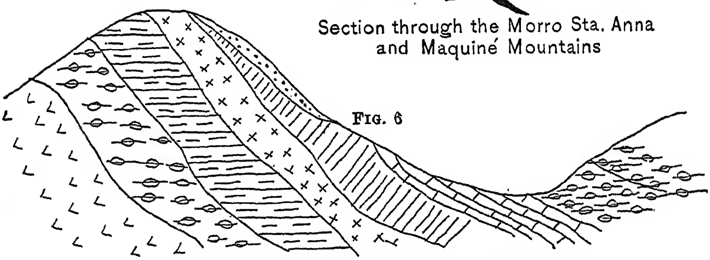


FIG. 6

Section through the Gongo Socco Mountains

Gneiss or Granite
Micaceous and Talcose Schists
Schistose Quartzites
Auriferous Quartz Lode
Argillaceous Schists
Itabirite
Lines of Auriferous Jacutinga in Itabirite
Limestone
Canga, or Iron Ore Conglomerate

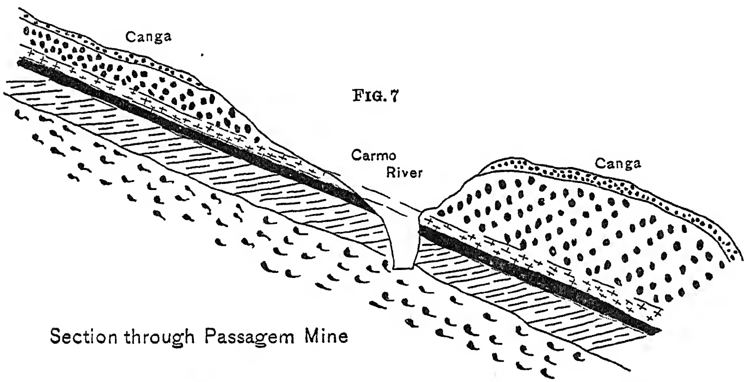
Geological Sections in Minas Geraes, Brazil.

called to the auriferous lodes; and the operators, having at that time no knowledge of mining proper, treated the outcrops of these for some time as they had the alluvial deposits. The difficulty of following the lodes in depth, however, obliged them

to resort to mining. Cross-cuts were run in from the hillside; and, the lode being reached, it was excavated in irregular chambers from below upwards by a sort of overhand stoping, pillars being left to secure the hanging-wall. No timbering was employed, the levels being made with the section of a gothic arch; and it is interesting to note that the itabirite, cut in this way, has stood unaltered to the present day. The lode-stuff was burnt, to oxidize any pyrites present; thrown into water while hot, to make it more friable; and then crushed by abrasion between two pieces of the hard quartzite.

In this way the whole length of auriferous ground between

FIG. 7



Section through Passagem Mine

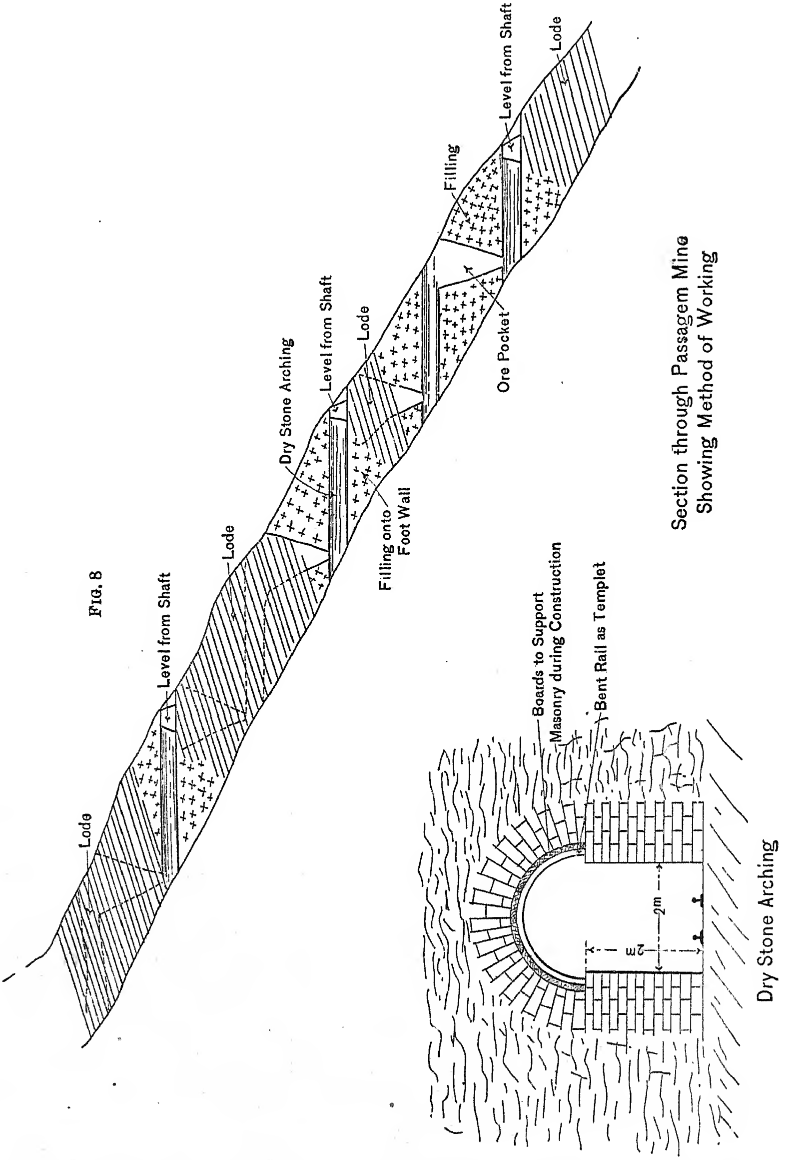
Iron Ore Conglomerate
Itabirite
Argillaceous Schists
Quartz Lode
Schistose Quartzites
Micaceous and Talcose Schists

(The strata occur in the order named, beginning at the top.)

Ouro Preto and Marianna, several kilometers in extent, was worked out above water-level by the early miners. (Fig. 11.) At some points, towards the summit of the mountain, cross-cut levels were driven; and there is reason to believe that some of these were used as dwellings. The concentrates from both alluvial and underground workings were treated in a sort of long tom, known as the *canoa*, still much used by the river-washers, and consisting, in its simplest form, of a sluice about 2 m. long, and inclined at about 20°, on which is laid a blanket of native manufacture held in position by two sticks. A stream of water is allowed to run over this; and, the concentrated auriferous

gravel being agitated at the head of the sluice, the earthy matter is carried over and the gold caught by the blanket. A final

FIG. 8



Section through Passagem Mine Showing Method of Working

washing in the *batea* of the gold caught on the blankets leaves with it only a small quantity of magnetic oxide of iron, which is separated by a small magnet.

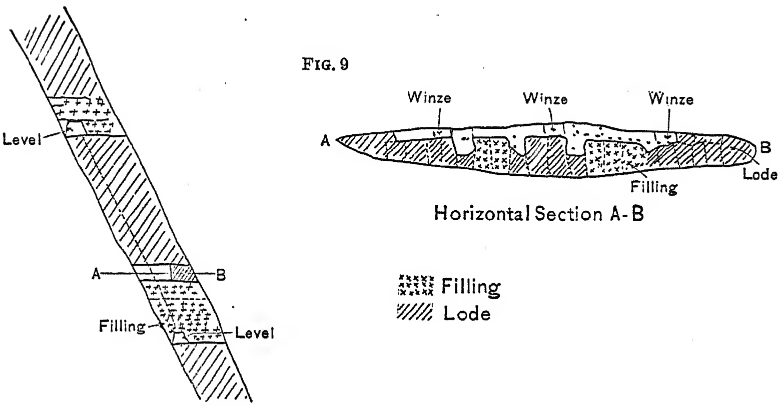
Figs. 12, 13 and 14 show an abandoned mine and primitive methods of working.

VI. Descriptions of Individual Mines.

1. *The Gongo Socco Mine.*

The decadence of the gold-mining industry towards the end of the eighteenth century was doubtless due, in great part, to the ignorance of the natives regarding proper mining methods. In 1820, an English company began to work the Gongo Socco mine; and the great success of this first venture caused quite a

Fig. 9



Vertical Section through Faria Mine

boom in gold-mining. Many other foreign companies came into existence, the majority of which, having been for various reasons unsuccessful, do not merit special mention. The Gongo Socco mine, however, was of such importance that a short description of it may be interesting.

Gongo Socco is situated on the Central railway of Brazil, about 30 kilom. east of Sabara, and about 1000 m. above sea-level. The gold was found in *jacutinga* seams in friable itabirite rock. The mountain containing the outcrop runs E. and W., and consists of granite overlaid with micaceous schists, quartzites, itabirites, and limestones—all dipping about 45° S. This geological section, it may be mentioned, agrees well with that in the neighborhood of Ouro Preto. The auriferous *jacutinga* varied in width from extreme thinness up to 15 centim.,

and in the wider parts the center was found to be composed in great part of laminated masses of gold, weighing from a few grammes up to several kilos. Two-thirds of the gold extracted was found in masses, plates and threads, and one-third disseminated through the adjoining matrix. Captain Lyon, the manager, reported in 1830 that one man had taken out a capful of stuff which yielded 10 kilos of gold. Other remarkable finds were reported as follows:

Period.	Gold, kilogrammes.
From January 19 to 24, 1829,	53.8
From February 25 to 26, 1829,	47.6
From September 22 to 28, 1829,	193.0
From January 21 to 22, 1830,	52.6

The whole of the itabirite formation was found to be slightly auriferous, but not sufficiently so to be profitably worked. The *jacutinga* seams analyzed (Henwood, *op. cit.*, p. 261) as follows:

	Per cent.
Peroxide of iron,	97.00
Silica,	1.60
Alumina,	1.10
Oxide of manganese,	0.60

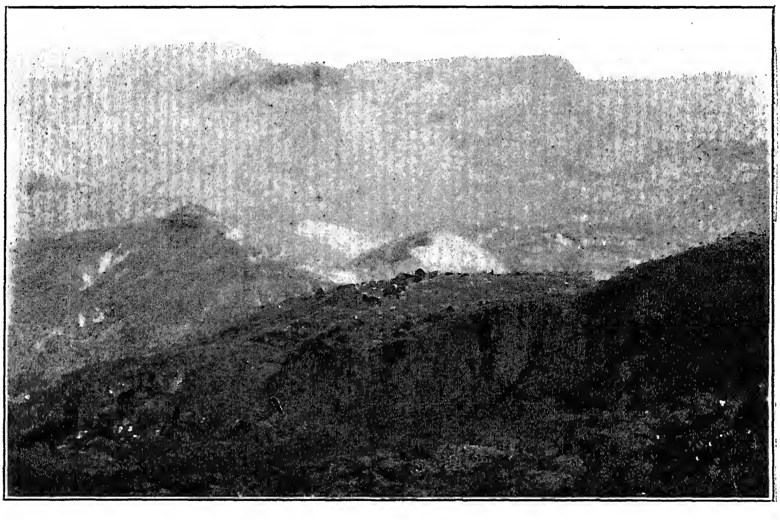
The richest part of the mine, known as the eastern shoot, seems to have furnished the greater part of the gold. Apparently the mine was not rationally worked, the absence of all filling rendering the consumption of wood enormous. The most resistant timbers were crushed by the pressure of the friable itabirites, and had to be renewed continually. The richer portions of the auriferous seams were simply washed in the *batea*, and the "run of mine" was put through the mills. These were of native manufacture. The stamp-heads and dies (made in the Catalan forges near by) weighed 130 kilos each, and ran at 60 blows per minute, crushing 3 tons of ore per head per day. The gold was collected on strakes covered with uncured hides and laid at an inclination of 7 per cent., the concentration being finished, as usual, by hand in *bateas*.

This mine was sold to the English company for £90,000; and notwithstanding the high price, and the almost proverbial extravagance and robbery attending the operation, it was very prosperous for a time. Between 1826 and 1839 eleven tons of gold (worth £1,300,000) were taken out. Dr. Gardner, a traveler

FIG. 10.

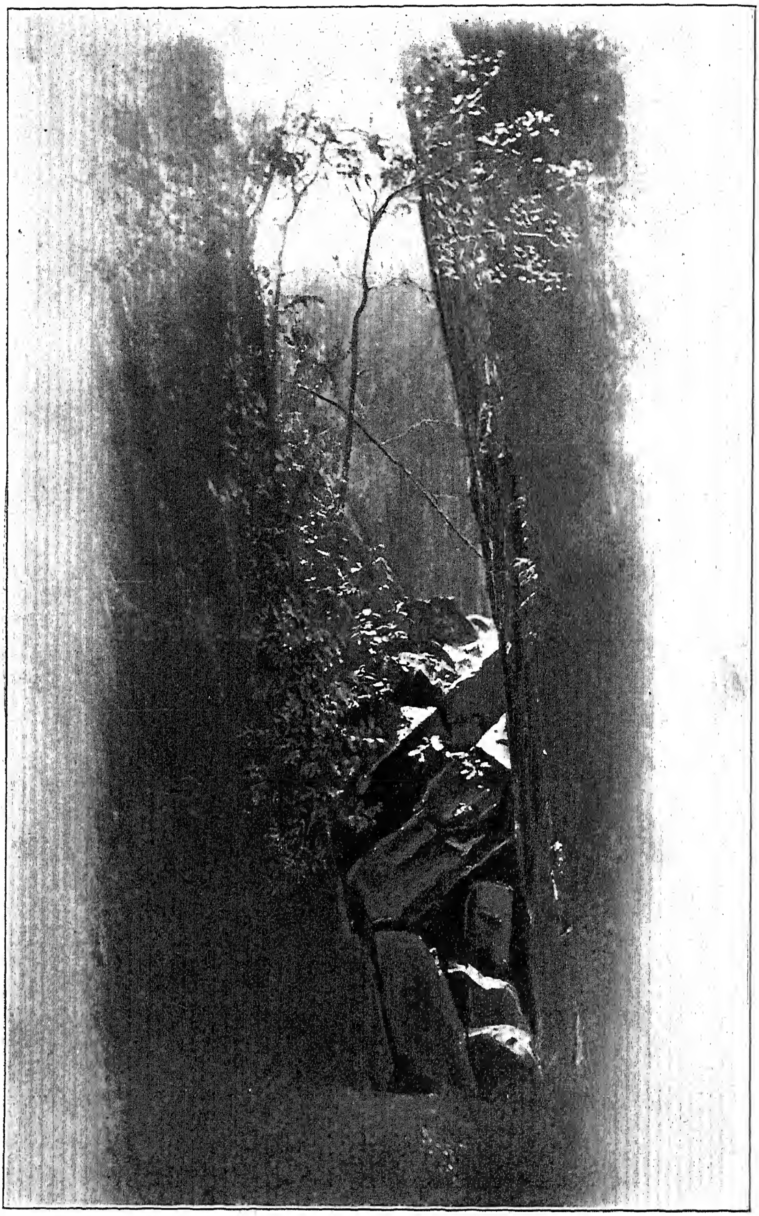
The City of Ouro Preto, Brazil.

FIG. 11.



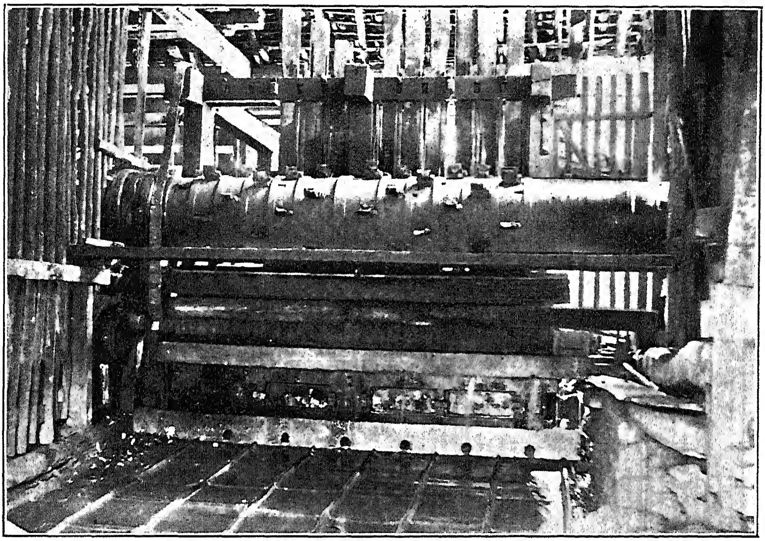
Old Open-cast Gold-Workings, Ruins of Villa Rica in the Distance.

FIG. 12.



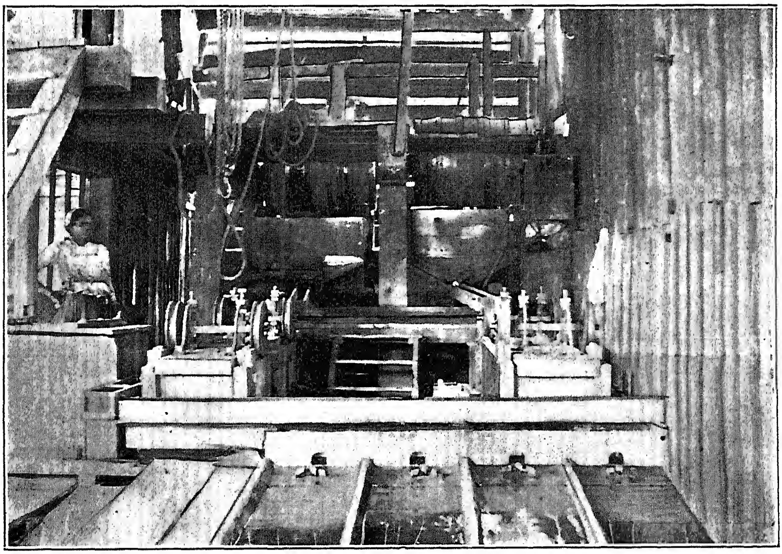
View of the Crush of 1845, which Caused the Abandonment of the Catta Branca Mine.

FIG. 13.



The Pary Mine, Native Mill.

FIG. 14.



The Pary Mine, Amalgamating Plant.

visiting the mine in 1840, found the two lower levels under water; and it is more than probable that the lack of proper pumping-appliances was finally responsible for its shutting down.

Table I. gives the yield in gold from 1826 to 1856.

TABLE I.—*Production of Gold at the Gongo Socco Mines, 1826–1856.*

Year.	Depth of Mine. Fathoms.	No. of Men.	Gold Production. At the Washing-House. Kilos.	At the Stamp-mill. Kilos.	Total. Kilos.
1826	3	450	207	.....	207
1827	7	.....	750	.....	750
1828	14	.....	396	.....	396
1829	21	782	1,421	143	1,564
1830	25	.....	1,047	88	1,135
1831	27	.....	909	223	1,132
1832	34	794	1,029	539	1,568
1833	41	776	668	447	1,115
1834	48	611	349	268	617
1835	48	609	212	198	410
1836	48	675	205	168	373
1837	48	772	350	172	522
1838	55	751	236	153	389
1839	55	758	322	196	518
1840	62	801	177	206	383
1841	62	714	136	210	346
1842	62	683	142	228	370
1843	68	632	37	189	226
1844	70	685	88	126	214
1845	70	653	20	71	91
1846	70	624	22	88	110
1847	70	575	2	57	59
1848	70	324	....	64	64
1849	70	262	....	59	59
1850	70	270	......	52	52
1851	70	271	......	39	39
1852	70	316	....	40	40
1853	70	449	....	48	48
1854	70	520	....	36	36
1855	70	458	....	25	25
1856	70	447	....	29	29
Total........	...	.....	8,725	4,162	12,887

Modern Mines.

The most important mines in operation at the present time are as follows:

(1) Morro Velho, owned by The St. John del Rey Gold Mining Co.

(2) Passagem, owned by The Ouro Preto Gold Mining Co. Figs. 7 and 8.

(3) Faria, owned by The Faria Gold Mining Co. Fig. 9.

(4) São Bento, owned by The São Bento Gold Estates Co.

(5) Sta. Quiteria, worked by The Anglo Brazilian Gold Mining Co.

(6) Morro St. Anna, owned by The Ouro Preto Gold Mining Co.

(7) Itabira, owned by Companhia Braziliera das Minas de Itabira.

(8) Carrapato, worked by Carrapato Gold Mining Co.

(9) Juca Vieira, owned by Lathom Gold Mining Co., Ltd.

(10) Florisbella, owned by Companhia Aurifera de Minas Geraes.

The companies Nos. 7 and 8 are native; all the rest are English.

(1) *The Morro Velho Mine.*—The St. John del Rey Gold Mining Co., Ltd., was originally formed with a capital of £165,000 to work a property near the town of that name. In 1834 this property was abandoned and that of Morro Velho acquired. The Morro Velho lode is in the form of an oval column, and consists of quartz, magnetic iron pyrites, calcite and dolomite, with some pyrites and mispickel. It runs down in the midst of (according to Dr. Derby) a highly sheared calc schist, with a dip of 45°, an E.–W. strike, a thickness varying between 1 and 35 m. in width, and a length of more than 170 m. It appears to have been worked from the very earliest times, although the only reliable information concerning it dates from the end of the eighteenth century, when it was worked by a Catholic priest, named Freitas. It gave very good results; but, like the majority of the native mines, it was, by reason of the ignorance of rational mining methods, stopped early in the last century. Auguste de St. Hilaire, the famous French traveler, passing, in 1818, through the village of Congonhas, now known as Villa Nova de Lima, wrote in his Journal:

"*Congonhas doit sa fondation a des mineurs attirés par l'or que l'on trouvait dans les alentours, et son histoire est celle de tant d'autres bourgades. Le precieux metal s'est epuisé, les travaux sont devenus plus difficiles, et Congonhas n'announce actuellement que la décadence et l'abandon.*"

This conclusion was somewhat hasty, for the history of Morro

Velho during the last 70 years has proved that the former abandonment of a mine in Minas Geraes does not by any means prove that it was worked out. The early work of the English company which purchased the mine in 1834 simply followed the method of its predecessor, and resulted in the formation of an immense chamber, the hanging-wall being held up by huge timbers and pillars of low-grade ore. In 1867 a fire caused heavy falls, which resulted in the temporary abandonment of the mine. During this first period the mine produced about 28.5 tons of gold from a mineral assaying 26.5 grammes per ton, of which only 15.5 grammes were recovered. On the paid-up capital of £135,000, the dividends between 1842 and 1867 were at the rate of 25 per cent. per year, a total amount of £896,000 being distributed. Later, it was decided to reopen the mine; and to this end the capital was raised to £233,000, and two vertical shafts were sunk to the lode. These were completed in 1874, but the system of work followed was little better than before. It consisted in leaving pillars of low-grade ore, or, when this was not possible, putting in huge stulls to hold up the hanging-wall. As the mine became deeper the pressure on the timber increased enormously, and the stulls were crushed daily. During 1886, the pressure became so great that a part of the hanging-wall fell, destroying the mine again. From the date of the reopening to the time of the crush, 30 tons of gold had been produced, and between 1875 and 1884, dividends amounting to 30 per cent. per annum were declared, a total amount of £556,600 being distributed. The total value of the gold extracted from 1834 to 1884 was £5,500,000.

After this new disaster, the present manager, Mr. Chalmers, suggested the reopening of a new mine below the old one; and two vertical shafts were sunk, 17 m. apart and 43 m. from the lode, in order to keep the exit safe in case of accident. They were completed in about 3 years to the depth of about 686 m., a rate of 24 m. per month being attained. An adit-level 364 m. long, crossing the shafts 98 m. from the surface, was run for connection and haulage. In the first part of the adit-level, and for 45 m. in the shafts, the enclosing schist was decomposed and soft, so that lining was indispensable. All drilling was done by hand, machines not proving successful, by reason of the nature and dip of the rock.

It was decided to adopt in the new mine overhand stoping and filling. From the shafts, levels are run the entire length of the lode, and connected vertically by winzes.

Owing to flattening of the lode, underlie-winzes have been adopted, which follow the course of the lode. The whole width of the lode is excavated to the height of about 5 m., after which the level is arched over with brick and concrete. Overhand stoping is then carried on, filling being introduced regularly, to keep the men up to the working-face. The filling from the surface was first raised into the stopes by the heavier descending mineral, actuating a counter-balance hoist governed by a friction brake; but now suitable double- and single-drum engines are employed for hauling and winding. It was the custom at one time to return the ore, after treatment, to the mine as filling; but the oxidation of the pyrites generated so much heat that this practice was abandoned. It is an interesting fact that while, in the old mine, water constituted one of the chief difficulties of working, the present mine is perfectly dry.*

To the unwatering of the old mine, which contained at times more than 20,000 tons of water, Mr. Chalmers, the manager, early gave particular attention. At first he employed a bailing arrangement, but as this only handled the water above the crush, he proceeded to erect hydraulic machinery to unwater the old mine through the new one. The hydraulic arrangement for actuating the pumps is driven by water brought down the shaft to the adit-level in a 30-centim. pipe, under a head of 150 m. The pump-rods are 16 centim. in diameter at the top and 11 at the bottom, and their total length is 652 m. The counter-balance boxes carry 35 tons each, the total weight of the pump-rods, etc., being calculated at 70 tons. The pump makes 6 strokes of 3.3 m. per min.

The tapping of the overlying body of water was effected by an air-driven diamond drill, fixed in a specially-designed cannon, which permitted satisfactory drilling, while at the same

* The importance of this fact cannot be overestimated, as although in the deeper levels the cost of haulage will increase, that of pumping decreases. It is interesting to note that in this respect this Brazilian mine is similar to those in the Transvaal, according to Mr. J. Hays Hammond in his paper on "Gold Mining in the Transvaal," *Trans.*, xxxi., 817.

time guarding against disaster due to an unexpected in-rush of water. From a dead heading on the sixth horizon, 4 holes of an average length of 41 m. were driven upwards to where the old excavation was supposed to exist. They traversed, for the most part, ore and micaceous schists, but none of them cut into the old mine. The progress of the drill varied greatly: in pure quartz it did not exceed 5 centim. per day, though in the schists sometimes as much as 4.5 m. were drilled in 24 hours. The fifth hole encountered water 96 m. from the stuffing-box, in May, 1896; the pressure verified on that occasion being 45.5 kilos per sq. centim., or 629 lbs. per sq. in. In a comparatively short time the water was emptied down to the bore-hole; and in July, 1901, the old mine had been completely drained, and was kept well in hand by the pumps.

Except in the case of the enclosed electric-motor fans, which are placed in permanent roadways, and consequently in protected positions, all power underground is given by air compressed at the mouth of the adit. This general substitution of compressed air for electricity (first used) was made (though the compressed air is the more costly of the two) on account of the electric motors which were installed being affected by the heavy blasting-operations.

The winding-engine is a hydraulic one, driven by hurdy-gurdy wheels under a head of 60 m. Although originally designed for an output of 6000 tons per month, it is actually handling more than double that output. The drums are parallel, 3.35 m. in diameter, and the rope is a 2.5-centim. "lock coil."

The journey in the shaft occupies about 2.5 minutes. The stone leaves the adit in the cars which are filled in the stopes. They are taken up an endless-chain incline, and, after weighing, are discharged by a tipple to a 7-centim. grizzly, the large pieces being picked off and thrown into a large Blake-Marsden rock-breaker. The broken stone, together with that from underneath the grizzly, enters a trommel with 5-centim. holes; and the fine ore passing through this goes direct to the bucket-elevators. The coarse stone falls upon a revolving-table, where it is picked over by women, the rejected pieces being placed on the extreme edge, and, as the table revolves, swept off into a car which goes to the dump. The good min-

eral is raked off into three small Blake-Marsden rock-breakers, with apertures 35 mm. wide, and from these it passes by chutes to two bucket-elevators, which deliver into a saddle-back car. This latter distributes the ore to the storage-bins, which are of the usual type, fitted with "Challenge" feeders. The mill constructed by Messrs. Fraser & Chalmers has 120 stamps, weighing 340 kilos each. The drop and speed vary according to the class of ore, but may be taken as averaging 20 centim. drop and 90 blows per minute. From 2.5 to 3.25 tons per head are crushed per day, or say 10,000 to 13,500 tons per month. The mortar has a double discharge, through a 60-mesh gauze, the screens being corrugated, to give strength and larger area. The pulp leaving the screens passes into distribution-boxes, which deliver it by spouts, through which the feed can be regulated, to the three-decker strake-frames. These are hung on centers over a sloping cement floor, on which the concentrates fall as the mechanical washer removes them from the canvas. This washer is a traveling siphon, which tilts the frame from the horizontal to the vertical position, and, by means of a row of flat jets, completely cleans each strake in a few seconds, the supply of pulp being automatically cut off while the strakes are being washed. By this arrangement one man and two boys can attend to some 80 frames, arranged in two lines. The tailings from the first row are led by pipes to the second row, while the concentrates run off the floor and are led away to be treated on similar strakes at a lower level, until the bulk is reduced to about 1 per cent. The concentrates from the second row are reserved for further treatment by the "oxygen" process, while the slimes, which constitute 70 per cent. of the total weight, are rejected. The rich concentrates (formerly treated by barrel-amalgamation) are now passed over small tables, until the gold is sufficiently pure for melting into bullion. The mechanical arrangements and general plan are such that all these operations of concentration are carried out with the minimum expenditure of power and labor. About 65 per cent. of the gold-contents are removed mechanically, and 15 per cent. by the oxygen process, the remaining 20 per cent. being at the present time lost, though it will be treated in the future, if the value of the mineral remains the same.

The "oxygen" process was elaborated by Messrs. Chalmers

& Wilder at Morro Velho, after they had tried other well-known processes and found them inapplicable to this refractory ore. The writer is not permitted to make public the details of this process; but it may be described briefly as a modification of the cyanide process, with agitation and air forced through the liquid to facilitate the solution of the gold.

All the machinery connected with the mill is driven by a Pelton wheel 2.36 m. in diam., actuating a wire rope 2 centim. in diam., which travels at a velocity of 1600 m. per minute. The tension on the rope, usually obtained by a guide pulley at the expense of much loss in friction and damage to the rope, is in this instance effected by the Pelton wheel, with its driving-pulley, being mounted on a sliding bed-plate, and the water-jet being telescopic. By simply releasing a few bolts holding the bed-plate and actuating a screw, any required adjustment can be attained for the requisite tension on the rope.

Power for driving the machinery at the mine is obtained:

1st. By the utilization of power from the water-courses (60 miles in extent) bringing water direct to the plant.

2nd. From three electrical transmission-plants, two of which are continuous-current, transmitting 250 H. P., and one high tension three-phase, transmitting about 150 H. P.

3rd. From semi-portable steam-engines, using wood as fuel, and only employed when the supply of water falls off.

The three-phase alternating-current has proved much more satisfactory than the continuous-current; and it has now been decided to lay down an additional high-tension three-phase plant of about 300 H. P. It was at one time intended to transmit at low tension; but this had to be abandoned, on account of the cost of the copper cables. Another more important scheme, to transmit electrically about 1500 H. P., has been left in abeyance for the present, owing to the necessity of having as soon as possible an increase of power to take the place of the steam-engines. The superintendent, however, is of opinion that the scheme must eventually be carried out, if the mine is to be worked to a great depth economically, and all hand-drilling replaced with power-drills. The cost per H. P. per day, with wood as fuel, is 2*s.* 3*d.*, and with water, only 3*d.*

The ore is very irregular in its gold-contents. The pure quartz is seldom auriferous, and the pure pyrites (unless it be

arsenical) hardly ever rich. A mixture of quartz with arsenical pyrites and pyrrhotite, in the presence of the carbonates, dolomite, etc., seems to be the most favorable matrix for the gold. The enclosing rock, though generally pyrites-speckled, contains only a small quantity of gold at the contact, equivalent to about from 3 to 5 grammes per ton. Although Henwood declared that the ore became poorer in depth, this has been proved to be a fallacy by the results obtained since the reopening of the mine. They compare favorably with those of 1858 and 1860, which may be considered as typical, and in which the assay-value ran from 20 to 28 grammes per ton of ore, the extraction then being 11 to 18 grammes per ton, or about 60 per cent. of the gold-contents. An analysis of the ore gives the following result:

	Per cent.
Silica, as quartz,	24.10
Iron, in pyrites, pyrrhotite, etc.,	31.47
Arsenic, in mispickel,	2.32
Sulphur, in pyrites and pyrrhotite,	13.52
Alumina, in clay-slate,	3.00
Oxide of manganese,	1.30
Lime, in dolomite, calcite, etc.,	3.08
Magnesia, in dolomite, etc.,	6.51
Copper, in copper pyrites,	.21
Carbonic acid and oxygen in dolomite, etc.,	14.49
	100.00

The proportion of pyrrhotite or magnetic pyrites in the ore averages 28.5 per cent. The bullion is worth 64*s.* to 70*s.* per ounce, and is .790 to .810 fine, the rest being silver.

The consumption of lode-ground per annum is about 30 m. of vertical height. For the year ending March, 1900, the average yield was about 23 grammes of bullion per ton, equivalent to 53*s.* 2.5*d.*, of which 41*s.* 5.5*d.* was recovered on the strakes, and 11*s.* 9*d.* by the oxygen process. The cost of extraction for the same period was 31*s.* 11.25*d.*, made up of 25*s.* 2.5*d.* for working-cost, and 6*s.* 8.75*d.* for plant-renewals. The recovery was 81 per cent. For the year ending March, 1901, the value of the gold extracted per ton of ore was 46*s.* 6.5*d.*, of which 37*s.* 3.75*d.* was recovered by the strake process, and 9*s.* 2.75*d.* by the oxygen process. The total cost of extraction was 30*s.* 5.5*d.*, of which 25*s.* 1.5*d.* was working-cost, and 5*s.* 4*d.* plant-renewals. The working-cost may be divided as follows:

	s.	d.
Mining department, ...	10	10.5
Reduction department, ...	7	10.25
Engineer's department, ...	1	10.75
Stores, offices, etc., ...	4	6
	25	1.5

The somewhat lower results of 1901 are due in a great measure to a barren piece of lode which replaced the rich ore between the eighth and ninth levels. This occurrence is not of very great importance, since the same thing happened in 1882 at a higher level.* The ore has already been found to be of average value below the tenth level; so that there is little doubt of its continuing normal in the future. Another fact that contributed to the lower yield was the smaller percentage of ore rejected at the mill, namely, only 4.6 per cent., as against 7.4 per cent. in 1900. In every other respect the year ending March, 1901, was a record one; 152,238 tons of ore being raised, and 140,855 tons crushed, and the extraction amounting to 99,197 oz. Troy, equivalent to £327,663, or an average of 0.7 oz. Troy per ton of ore.

Some time ago an underlie-shaft was started to follow the lode along its dip, and serve for hauling from the lower levels. It has been found, however, that the inclination of the lode has become appreciably less, and consequently the shaft would, if continued, run into the lode. It will now only be used for handling the ore down to the twelfth level, and a hauling-level and vertical shaft will be made to handle the ore from all levels below that. The total depth of the mine from the mouth of the shaft to the twelfth level is 1030 m. The large ore-body and its uniform quality, together with the present excellent management, augurs well for the future of this mine, which is a model of its kind, and a monument to the engineering skill and organizing ability of Mr. Chalmers.

(2) *The Passagem Mine.*—This mine (Figs. 7 and 8), belonging to the Ouro Preto Gold Mining Co., and situated about 7 kilom. E. of Ouro Preto, is the one which Von Eschwege worked early in the eighteenth century. The ore occurs in shoots of

* The distinguished American Geologist, Dr. Orville A. Derby, who has made a life-study of Brazilian mineral formations, is distinctly of opinion that there has been no evidence as yet of the lode pinching out.

quartz and arsenical pyrites, with smaller quantities of magnetic and ordinary pyrites, intercalated between friable itabirite on the hanging-, and schistose quartzites on the foot-wall. The latter are sometimes interposed in the lode, and occasionally replace it altogether. The lode strikes NE.–SW., dips 20° SE., ranges in thickness between 2 and 15 m., and contains varying proportions of gold. Near the foot-wall, where arsenical pyrites and tourmaline abound, it runs as high as 200 grammes, while the poorer ore yields only 2 to 3 grammes, of gold per ton. Mining is now done through two inclines sunk on the dip; and a third, approaching completion, will open up the lower and more easterly part of the main shoot. The levels, 16 m. vertically (or 50 m. on the dip) apart, are run along the hanging-wall of the ore-bodies. The ore is extracted from overhand stopes, afterwards filled with material from the schistose quartzites, a considerable quantity of which is necessarily broken down in the ordinary operations of mining. In order to let the filling rest directly on the foot-wall, it is the custom first to mine, by underhand stoping, the triangular piece of ore below the level and between it and the foot-wall; after which, the lode is taken out to the full height of the level from hanging- to foot-wall. The foot-wall side of the level is then built up, roads being left to the foot-wall, at intervals, for the extraction of the stone from the stopes below. Stoping is then carried upwards (chutes and pockets being made in the filling for the ore excavated) till a height of 8 m. is reached, when another small road is made to the foot-wall, and the second half of the stope is worked out in the same way as the first. This double handling of the ore from the upper half of the stope is necessary because the inclination of the lode is not great enough to enable the ore to fall by gravity to the tramming-levels. All the roads, chutes, pockets, etc., are built of the stone from the schistose quartzites. This system of filling, introduced by the superintendent, Mr. Gifford, in place of the old chamber-and-pillar system, which left the worked-out parts of the mine often in a dangerous state, has been found economical and satisfactory, dispensing altogether with the use of timber in the mine. Where the lode is very wide, the filling and piling becomes somewhat expensive—waste material having to be brought from the more distant

parts of the mine. In the tramming-levels a narrow-gauge track (40 centim.) is used, which permits the introduction of very sharp curves, necessitated by the irregular-shaped ore-bodies. Air power-drills are used in driving the levels, but hand-drills do better in the stopes. The ore trammed from the levels is fed into pockets over the inclined shaft, and from there hauled to the surface. The lowest levels are now some 600 m. below the surface, along the incline; and 6000 tons per month are excavated, carrying from 12 to 15 grammes of gold per ton.

This ore must be classed as refractory, the gold being contained mostly in arsenical pyrites. The mineral is trammed from the shaft-mouth to the picking-floor, where about 10 per cent. of the rock is rejected. The rest passes through Blake crushers, and is then distributed to an 80-stamp Californian mill. The pulp from the batteries is passed over a short length of blanket-strakes, to retain the rough free gold, and over 32 Frue vanners, which separate the pyritic concentrates containing the finer gold. Owing to the arsenical nature of the pyrites, amalgamation was very unsatisfactory and had to be abandoned. The product from the blanket-strakes is re-concentrated to a small bulk, and the rough gold is separated in *bateas*. All the residues from the re-concentrates and from the *bateas*, together with the concentrates caught in the Frue vanners, are then roasted in reverberatory furnaces, and the gold is extracted by the barrel-chlorination process. By reason of the high cost of roasting, cyaniding, without roasting the raw concentrates, was attempted, but for a long time without satisfactory results. Recent trials of a modified cyanide process, including agitation, have had much better success; and the latest information indicates that, in the near future, this process will replace chlorination.

For the year ending June, 1900, the yield in gold-bars from 63,644 tons of ore was 11.3 grammes per ton, as against 9.45 grammes for the previous year; or, expressed in money-value, 26*s.* 10.5*d.* as against 22*s.* 3.5*d.* per ton. The total extraction was 83.3 per cent. The expenses per ton of ore increased during the same period (largely, however, by reason of a rise in Brazilian exchange) from 20*s.* 8*d.* to 22*s.* 6*d.* The cost of treating the ore during the year under consideration was divided as follows:

Cost of Treatment per Ton of Ore, June, 1899, *to June*, 1900.

	s.	d.
Administration,	0	6
Mining, including development,	13	1
Milling and concentrating,	3	11
Chlorination,	1	10
Gold-tax,	1	1
Maintenance and repairs to plant,	1	5
Incidental expenses,	0	8
	22	6

From April, 1884, to December, 1900, the yield of 617,129 tons of ore treated was 6,862,572 grammes of gold, an average of 11.12 grammes per ton.

During the year ending Dec., 1901, profits were diminished by the increase in the value of the National currency (in which, of course, expenses were mostly paid). The gold-value extracted was 27*s.* 2*d.* per ton, as compared with 26*s.* 10.5*d.* for the previous year; but the cost, by reason of the higher exchange, was 25*s.* 2*d.*, as compared with 22*s.* 6*d.* per ton.

(3) *The Faria Mine.*—This mine (Fig. 9) is situated near the station of Honorio Bicalho, on the Central railway of Brazil. The ore-body is a chimney or oval column, like that at Morro Velho, intercalated between micaceous schists. It strikes NE.–SW., dips 60° SE., is from 2 to 10 m. wide and 50 m. long, and consists of quartz and auriferous pyrites, with a certain amount of hydrated oxide of iron and argillaceous schist. An incline following the dip, sunk in 1897, has reached a vertical depth of 150 m., or 250 m. on the incline. The hoisting is effected by electrical power. The mine was opened up by levels run in along the center of the lode from end to end, and connected by rises. Overhead stoping followed, the ore being taken out in slices about 2 m. thick. The friable nature of the hanging-wall makes it necessary, sometimes, to work the slice in sections, with filling introduced from outside, and kept tightly packed up—only a road being left along the foot-wall to serve as communication from one part of the stope to the other. Powerful pumps, with cylinders 35 centim. in diam. by 2.1 m. stroke, working at 7 strokes per minute, were erected when the shaft was sunk, and were able at the time to handle all the water; but as sinking has gone on, the quantity has so increased as to overpower them at times. An adit-level, which will serve

to drain the mine, will probably be driven in the near future to a point on the lode 100 m. below the present working-level.

The method of reduction first adopted was almost identical with that in use at the Passagem mine; but after a little experience in milling the ore it was found that, although it contained from 20 to 25 grammes of gold per ton, only about 48 per cent. of this was extracted, by reason of the argillaceous character of the gangue and the consequent formation of a large quantity of slimes which carried off the gold. To remedy this trouble, a cyanide-plant was erected to treat the tailings by percolation, and the slimes by Johnston filter-presses and agitators. This process has given satisfactory results, though some difficulty has been caused by slow filtering. The pulp is first passed over amalgamated plates, and then into two *spitzlutten*, which separate the concentrates from the tailings, the former going to boxes. The contents are allowed to dry somewhat before being cyanided. The tailings are passed through 2 *spitzkasten*, which separate the slimes; and these pass to settling-tanks for treatment by the Johnston filter-press process, the tailings, together with the concentrates, being treated by the ordinary percolation process. The writer is informed by the present manager, Mons. A. Triana, that good results are obtained—the extraction of gold per ton for the month of November, 1901, having been as follows:

Extraction per Ton.

	Per cent.
On the amalgamated plates,	29.08
By the cyanide percolation process,	51.62
By the Johnston filter-press process,	4.57
Total,	85.27

The extraction by the cyanide treatment reached 90 per cent. on the sands and 55 per cent. on the slimes; and the proportions of concentrates, tailings, and slimes may be taken as 20 per cent., 30 to 35 per cent. and 45 to 50 per cent. respectively.

(4) *The São Bento Mine.*—This mine is situated near Santa Barbara. The lode, which is intercalated in the micaceous schists, is composed of a series of shoots which outcrop for 2

miles along the ridge of the São Bento mountain. It strikes NE.–SW., and dips 66° SE. The lode-matter is siliceous micaceous iron-ore, with interstratified bunches of schist, ferruginous quartz, earthy iron-ores and limonite. It is about 13 m. wide, and although all of it carries low values in gold, only from 0.5 to 2.5 m., containing from 3 to 30 grammes per ton, is available for milling. The pay-mineral is found in one or more branches in the lode, the highest values being in a ferruginous saccharine quartz in the higher levels, and associated with arsenical and ordinary pyrites in the lower levels—the former being, no doubt, a result of the decomposition of the latter. Owing to the irregularity of the pay-ore, frequent assays are necessary to control exploitation.

Since the lode stands in a hill of considerable height, it has been possible to mine it hitherto by cross-cut levels, driven from the hillside, about 30 m. apart, vertically. Overhand stoping and filling is practised; and the ore is trammed to the mill, situated at the foot of the valley.

The oxidized character of the ore, the argillaceous gangue and the finely divided state of the gold would probably cause, in any treatment by a wet process, the formation of a large quantity of slimes. Hence a plant was erected for dry-crushing and direct cyanide-treatment. The ore is passed through Blake crushers and Gates rolls, and, after drying in a revolving dryer, passes through a mesh-opening of 1.5 mm. This coarse crushing has given satisfactory results, the extraction being about 86.6 per cent. It is open to doubt whether the process will work equally well with the sulphide-ore which will replace the oxidized mineral in the lower levels, though it has been found that the small quantity of sulphides encountered at present has no appreciable effect on the percentage of gold extracted. The average yield of gold per ton of ore, since the commencement, has been 13 grammes, equivalent to 32*s.* 4*d.*

Owing to the short time that mining operations have been carried on, and the consequent small output, the costs per ton of ore treated are somewhat abnormally high, as the following statement shows:

Cost of Treatment per Ton of Ore.

	s.	d.
Administration,	4	0
Duty and charges on gold,	1	11
Mine-development,	4	10
Stoping and mine-maintenance,	10	7
Transporting ore to mill,	0	9
Milling (steam-power),	2	10
Cyaniding,	3	0
Maintenance,	1	5
Total,	29	4

The production of the mine has hitherto been about 1500 tons per month; but this will soon be increased to 3000 tons or more, and the costs per ton will consequently be appreciably diminished.

Although the use of steam-power, from wood as fuel, is often convenient and economical during the opening of a mine, it constitutes afterwards an ever-increasing expense, in consequence of the progressive exhaustion of timber in the vicinity. The cost of wood at the São Bento mine is now about £80 per month; and it is therefore proposed to replace steam with power transmitted electrically from a neighboring waterfall.

(5) *The Sta. Quiteria Mine.*—This mine is situated a short distance from the São Bento. The lode is composed of limonite and quartz, and resembles that of São Bento, of which, in fact, it seems to be a continuation. It is interstratified between the talcose and graphitic schists, strikes NE.–SW., dips 45° SE., and varies in thickness between 2 and 10 m., of which only about 2 m. is pay-ore. The mineral is distributed irregularly in the lode. The ore of the highest value is a concretionary limonite, no doubt a product of the decomposition of pyrites which will be encountered at a lower level. The method of working hitherto pursued has been to follow the richer lines of the lode by means of levels extended from the hillside, in order to avoid the expense of haulage and pumping,—ventilation being effected by air-shafts to the surface. Hauling- and pumping-plants are now building, for the purpose of working below drainage-level. The mineral is trammed from the mine to a 10-stamp California mill, which (by reason of the friable character of the ore) crushes as much as 4 tons per head per day. The pulp is passed through a 30-mesh

screen, which has been found sufficiently fine to get a satisfactory extraction, while avoiding the formation of slimes. The gold is recovered by amalgamation with copper-plates in the mill and outside on tables. Of the copper-plates on the tables, two are silver-plated and two plain. Comparative tests, under similar conditions, show that the silver-plated plates give the best results. The tailings from the tables are passed over blanket-strakes, to separate any gold not caught on the tables, and the blanket-concentrates are treated by barrel-amalgamation. The complete process gives an extraction of about from 85 to 90 per cent., divided approximately as follows: 40 per cent. inside the mills, 35 to 40 per cent. on the tables, and 5 to 10 per cent. on the blanket-strakes, the total recovery being about 14 grammes of gold per ton of ore. The output of the mine is at present only about 1200 tons of ore per month, but it will soon be largely increased by an inclined shaft, which it is proposed to sink to the deeper levels.

(6) *Morro St. Anna and Maquiné Mines.*—A company was formed in 1862 to work the Morro St. Anna property, situated near Marianna. The lode carries quartz, with arsenical and ordinary pyrites, and occupies the same geological position as that of the Passagem mine, distant about 6.5 kilom., of which it is supposed to be the continuation. Soon after it was opened a rich outcrop was discovered near by, at Maquiné, where the gold was found to be contained in *jacutinga* lines like that of Gongo Socco. This auriferous ground had a strike of NE.–SW., and an inclination of 27° SE. Although it carried values over a width of from 10 to 20 m., the greater part of the gold was contained in a few thin seams of the *jacutinga* ore. During 1868, two and a half tons of gold were extracted (one lot of 103 tons of ore gave 127 kilos of gold), the average gold-value of the ground being about 15 grammes per ton. In 1867–68 the company distributed over 100 per cent. in dividends; but shortly afterwards difficulties were encountered in working the mine, owing to the friable character of the itabirite and the lack of a proper filling system to counteract it. Stulls of huge dimensions and of the most resistant wood were easily crushed by the non-cohesive mass of hanging-wall. Moreover, the mine was very wet, and, in the absence of adequate pumping machinery, was inundated several times. It was finally abandoned, at a

depth of 212 m. on the dip. The rich gold-bearing seams, which were distributed at the surface throughout the lode, had shown a tendency to concentrate in depth. This mine had much in common with Gongo Socco; indeed, the history of one may be taken as that of both. They were the only two *jacutinga* mines successfully worked by English capital.

Upon the abandonment of the Maquiné mine, attention was again directed to the original Morro St. Anna property proper; and, for the treatment of the ore, a plant, consisting of 20 California stamps, with Frue vanners for the concentration of the sulphurets, was erected; also a 5-ton Plattner chlorination-plant. Unfortunately, the capital of the company was not sufficient to develop the mine satisfactorily, and it was sold to the Ouro Preto Gold Mining Co., which is now taking steps to open up the large quantity of ore known to exist above water-level. The value, thickness, length, etc., of the lode are much the same as those of the Passagem mine, already described.

(7) *The Itabira Mine.*—The General Brazilian Mining Association was formed in 1868 to acquire, near the city of Itabira do Matto Dentro, three properties, all of which had been worked with great profit during the eighteenth century. The principal mine is that of Itabira, in which the gold is contained in thin seams of auriferous *jacutinga*, interstratified between the siliceous iron-schist and an enormous mass of massive itabirite, which forms the summit of the Pico de Itabira. The seams outcrop near the summit of the peak, strike NE.–SW., and dip 30° SE., gradually flattening in depth.

The above-named Mining Association did not succeed in reaching the auriferous seams, and went into liquidation in 1874, when the property was acquired by some of the original owners, who continued the work and crossed the seams a few months later. In 4 months thereafter, the small force employed extracted 20,626 *oitavas* (2,292 oz. Troy) of gold, worth £6000. Unfortunately, a heavy fall of rock in the shaft stopped operations, and the mine was abandoned.

The gold was nearly all found in very rich stringers of *jacutinga*, the ore from which was treated on small canvas strakes and in *bateas*. The poorer parts of the seam were treated in a stamp-mill of native manufacture.

The mines are now being worked by a syndicate; and a

shaft is being sunk with the intention of cutting the seams of *jacutinga* in depth.

(8) *The Carrapato Mine.*—This mine is situated near Caethe. Its lodes are for the most part of quartz and auriferous arsenical and ordinary pyrites, interstratified between talcose schists. The strike is about E.–W., and the dip 39°.

The highest gold values are found in a series of lenticular masses of quartz, varying in thickness from 0.5 to 3 m., and often containing visible gold at the contact with the country-rock, and samples from these taken by the writer gave 78 grammes per ton of ore. The largest lode, varying in thickness between 2 and 5 m., assayed, in an average sample, 12 grammes per ton.

(9) *The Juca Vieira Mine.*—This mine is near the last described; and its gold-bearing formation has much the same character, though it contains more visible gold and some sulphide of antimony. It is at present worked by the Lathom Gold Mining Co., which is erecting machinery for the economical treatment of the mineral.

(10) *The Florisbella Mine.*—This mine is near the station of Honorio Bicalho. It has several lodes of quartz, interstratified in the micaceous schists, striking NE.–SW., and dipping 45° SE. A sample taken from a shaft running through one of the shoots gave the high gold-contents of 157 grammes per ton; but the general run of the ore varies only between 8 and 20 grammes.

NOTE.—All the lodes in the last three mines have a tendency to be "bunchy," very rich mineral being found in places, while the average of the ore runs between 10 and 15 grammes. Although the lodes seem to be fairly constant in depth, their longitudinal extension is generally not very great.

VII. RIVER-DREDGING.

A detailed investigation of the alluvial deposits and the old methods of working them has made it clear to the writer that the important deposits in the beds of the rivers are to all intents and purposes still virgin. To the early explorers, the task of exploiting the beds of rivers was well-nigh impossible; but to-day there is nothing to prevent the overcoming of all difficulties by up-to-date machinery.

Gold, undoubtedly, exists in considerable quantity in the beds of the rivers. Almost everywhere, the *faiscadores* (*batea* washers) gain a livelihood by working the river banks during the dry season, and coffer-dams, constructed in the shallow margins of the rivers, enabled the early miners to get at some of the gold. In the majority of cases, however, three-fourths of the total area of the river-beds remained untouched.

The writer is decidedly of opinion that river-mining would be profitable, if carried on with the aid of suitable modern machinery. Owing to the depth of water and the irregular size of the gravel, the hydraulic elevator or centrifugal pump would not be applicable; but a modification of the bucket-dredger should prove successful. Large boulders and dead tree-roots, the bugbears of river-mining, are not likely to be encountered; whilst fuel sufficient for the necessities of the machinery could be easily obtained—or power could be transmitted electrically from some neighboring waterfall. Great care, however, would be required in prospecting the rivers and studying the conditions of work, in order to have the apparatus thoroughly fitted to local needs.

Several concessions have already been granted by the State Government to work the river-beds in the auriferous zone; and it is probable that in the near future a number of dredges will be set to work.

VIII. Land-Tenure.

The lands in the interior of Minas Geraes were originally the property of the Crown, and were distributed to officials as gifts or concessions in return for political services. But all minerals were regarded as the exclusive property of the Sovereign, and all the deeds contained clauses reserving the mineral rights. The *data*, or claim, already mentioned, and established by the Government at the commencement of the industry, served as a unit of title while the work was confined to placer-deposits; but when lode-mining began, it was decreed that the grants of *datas* should remain in force only so long as regular work was done on them. During the crisis, at the beginning of the last century, when all mining of importance was abandoned, the concessions were allowed to lapse, and only in a few cases renewed. Abuses of all kinds crept in; and, generally speaking, the mining code became a dead letter.

On the proclamation of the Republic, an article of the Constitution (copied in great part from that of the United States) declared all land freehold. The freehold tenure of land may be beneficial in many places; but in a new country like Brazil it has had the effect of creating almost innumerable difficulties in the development of the mining industry, because it placed in the hands of the owners of the freehold (often illiterate men) the power to decide whether mining should be carried on or not. Frequently the owners refuse to negotiate at all, or, with extravagant ideas, born in great measure of ignorance and suspicion, ask an altogether impossible sum for the mining right or freehold title. Under the old *régime* nothing of this kind obtained.

Any prospector, once he possessed the necessary license from the Crown, had the right to explore and mine anywhere, provided he indemnified the owner of the surface for any damage done to crops, etc., and paid him the percentage of the net profits prescribed by the Government.

Another source of difficulty is the fact that very often a property is owned in common by a number of heirs or partners, who prefer to leave it undivided rather than incur the expense of a judicial division, and who must therefore all join in any grant of permission to mine.

Mining properties may be acquired in the following ways:

1st. *By Option of Purchase at a Term and Price Fixed.*—This is the arrangement usually adopted by the prospector, who arranges to carry out all the exploratory work while the term of the option is running. To ensure the faithful performance of this contract a penal clause obliges the vendor to give up his property to the buyer, who, in turn, deposits a sum of money with the vendor, to be forfeited in case of the non-fulfilment of his covenant.

2d. *By Simple Leasing of the Land for a Number of Years, with Payment of a Fixed Royalty per Ton of Ore Excavated.*—Though very common, this method is not recommended, because of the legal difficulty of enforcement. There is a possibility that the owner may sell the property without regard to his contract or lease; and in that case the lessee can only claim against the proprietor with whom he made the contract, and *not* against the *new* proprietor.

3d. *By the Leasing of the Land for a Short Period with the Option of Purchase.*—This is a satisfactory way for a prospector to acquire a property, as it enables him to explore it thoroughly; and his only loss, if the contract is not carried out, is that represented by the amount spent in labor and machinery, the latter of which generally reverts to the owner of the land.

4th. *By the Purchase of the Mineral Rights Only.*—In Brazil this is not often done; because separate ownership of the soil and the mineral right is so very likely to cause much friction and bad feeling.

5th. *By the Purchase Outright of the Freehold.*—This practice is most generally followed; but it is well to note that there is always a possibility of having the title contested, if the negotiations are hurried through too quickly. Special care must be taken to see that the boundary-lines are correctly marked, as this has often been a source of contention. In case of a contest, it is always preferable to avoid litigation and come to some compromise.

At present, the average prospector works at a disadvantage. Very often it is only after making a find that he can enter into negotiations with the owner of the property, who then spreads far and wide the news that mineral has been found on his land, and thus attracts the attention of a capitalist, who may purchase outright, as the prospector cannot afford to do. The capitalist has no knowledge of the property, and no reason for buying it, except the fact that a prospector has found something there indicating mineral value, and a notion that what a prospector desires to get by option or lease is good enough for another man to buy at a venture. In other words, a prospector may be entirely unable to effect an agreement with the landowner *before* any discovery; and *after* a discovery, the fact that he made it gives him no preference.

It is now suggested that the underground mineral right shall be made to revert to the Government, unless the landowner shall have registered a mineral discovery, and performed thereon a certain minimum amount of work annually. This would protect the rights of discoverers, operating under Government licenses, as is done in Mexico, for instance.

After a property has been acquired, complete freedom from contest may be secured by proceeding at once to have it regis-

tered under what is known as the "Torrens Register." As soon as these proceedings are satisfactorily concluded, the Government takes upon itself the responsibility of defending the title and indemnifying any third parties for loss, if such be proved. The documents required in support of the petition are simple, and consist of plans and description of the property, as well as the titles. The district judge duly publishes the petition, and, if no objection is received within a certain time, he orders the registration to be made. In case protest is made, the suit which follows is specially abbreviated—an important consideration for any company about to begin mining operations.

The Government-tax on contracts is merely nominal, but the tax on transmission of title is generally high—amounting in Minas Geraes to 6 per cent.

It is particularly necessary that prospectors or others operating in Brazil should know the language thoroughly. It is one thing to mine or explore in one's own country, and quite another in the interior of Brazil, where language, customs and people are so entirely different.

IX. The Government and the Future of the Mining Industry.

At the beginning of the last century the gold-tax was 25 per cent., but it was gradually reduced, and finally withdrawn, as the decadence of the industry became general. By reason of the economic crisis caused by the depreciation in value of the staple product of the country—coffee—both the Federal Government and the Government of the State of Minas Geraes have begun to give much more attention to the encouragement of mining. All machinery and material for mines may now be imported free of duty, and the tax on gold exported has been reduced from 5 per cent. (at which figure it stood for some years) to 3 per cent. A commission appointed by the Government is now studying the mining laws of various parts of the world, in order to frame a code which will meet the legitimate needs of the industry, and afford assistance to engineers and others visiting the State to examine the conditions of mining, etc.

The ores of Minas Geraes certainly belong to the low-grade class; but the gold-field possesses many natural advantages,

such as healthy and moderate climate, permitting work at all seasons; facility of transport, abundance of water-power, cheap labor, and good timber, to say nothing of a sympathetic Government.

Of failures, this State, like every other gold-field in the world, has had not a few. Most of them, however, can be traced to incompetent technical or business management and the lack of adequate appliances. The rapid rise in Brazilian exchange last year, due to the economic attitude of the present Government, has indirectly caused some loss to the mining companies by increasing the gold-value of mining costs; but this was only natural, as the price of labor cannot adjust itself immediately to new conditions. In the writer's opinion, when the transition-stage has been passed, the general conditions will be more favorable than before.

The gold-product for the last few years is given in Table II.

TABLE II.—*Gold-Product of Minas Geraes.*

Year.	Grammes.
1896,	1,962,767
1897,	2,071,243
1898,	3,267,080
1899,	3,973,710
1900,	4,811,031
1901,	5,000,000 (approximately.)

It will be seen that the production has more than doubled in 5 years. According to the official returns of the gold taxed up to 1820, and similar data from the modern companies, the total product of Brazilian gold has exceeded £85,000,000—not a bad record.

The President of the State of Minas Geraes, in his recent message to the Congress, said he was convinced that the mining industry was destined to take the rank formerly held by the coffee-culture, and contribute largely to the financial regeneration of the State.

The Chemistry of Ore-Deposition.

BY WALTER P. JENNEY, E.M., PH.D., SALT LAKE CITY, UTAH.

(New Haven Meeting, October, 1902.)

CONTENTS.

I. THE REDUCING ACTION OF CARBON AND OF HYDROCARBONS.

Carbon has long been recognized as one of the most powerful reducing agents in the deposition of ores. Investigations, made by myself, of the zinc- and lead-deposits in Southwest Missouri, in the region centering about Joplin, where the formation of the metallic sulphides has been due to the action of bitumen, carbonaceous shales and bituminous coal, have afforded abundant evidence that the solid oxygenated hydrocarbons, particularly when in fine powder and in suspension in the waters circulating through the ore-bodies, are the most energetic and powerful reducing agents known.

Bitumen, liberated by the decomposition of the ore-bearing limestone, is found in the Joplin mines in all degrees of fluidity and hardness, dependent on the amount of oxidation it has undergone. From semi-fluid maltha it grades into partly oxidized mineral-pitch, which, by further oxidation, changes to hard asphalt, finally breaking up, from continued absorption of oxygen, into a fine powder resembling in appearance powdered coal. In this condition oxidized bitumen, from its light gravity, is transported readily in suspension in the underground circulating-waters.

Bituminous coal and black carbonaceous clays and shales occur as surface formations, often in intimate association with

the ore-deposits, and when broken up, crushed, and faulted by crustal movements, furnish organic matter in a state of fine division. This is borne by the surface-waters and redeposited, often in large masses, in the channels and spaces in the ore-bodies.

Apparently the only pure form of carbon occurring in the ore-deposits of the Joplin region is the charcoal, which is found in inconsiderable quantity in the bituminous coal; all other carbon is combined with hydrogen, oxygen and nitrogen.

All these hydrocarbons readily absorb oxygen from the air contained in the subaërial waters, and undergo at ordinary temperatures, even below ground-water level, a slow combustion, the ultimate product being carbonic acid and water. They deoxidize the circulating waters by consuming all the free oxygen; and they reduce to sulphides any sulphates that may be in solution. Even ferrous and ferric sulphates, on coming in contact, in solution, with any of the solid hydrocarbons, are at once re-formed as pyrite or marcasite,—minerals that reduce all other metallic sulphates, first, by being oxidized to ferrous sulphate, and then, by further absorption of oxygen, to ferric sulphate and limonite.

Bain, writing of these mines, says, "The widespread presence of bitumen has been already emphasized. The ground-water is one great reducing solution."* Nearly every observer in this field has recorded the association of bitumen with the zinc- and lead-ores.

In my paper on "The Lead- and Zinc-Deposits of the Mississippi Valley"† I called attention to the reducing action of bitumen and bituminous shales in the formation of the ore-deposits of the Joplin District, and noted the influence of organic matter in the rocks upon the selective deposition of the ores in certain beds in the Cambrian and Silurian of Central and Southeastern Missouri, and also of the Upper Mississippi lead-region.

In limestones containing organic matter, especially if the rock be easily dissolved by waters carrying carbonic acid, the efficiency of even so minute a quantity as a fraction of one per

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* *The Lead- and Zinc-Deposits of the Ozark Region*, by H. F. Bain, p. 159.

† *Trans.*, xxii., 171–225.

cent. of bituminous substances, in inducing the precipitation and crystallization of the ores, is very great. Small as the proportion of the carbonaceous matter may be, it is liberated by the rapid subterraneous erosion of the lime-strata, in quantity more than is required to consume the free oxygen in the ore-forming solutions, and to reduce all sulphates to sulphides. In limestones highly soluble in carbonated waters, two-tenths of one per cent. of any strongly deoxidizing material, as bituminous coal or bitumen, disseminated in the rock, appears to be ample to effect the reduction of the metals, and to induce the deposition of the ores in the special geological formation.

Compared with carbon, hydrogen has far greater reducing power, measured by the amount of oxygen consumed, for hydrogen, in the production of water, combines with three times the weight of oxygen that unites with carbon in forming carbonic acid. In fact, hydrogen stands first in reducing power, accomplishing nearly nine times the work of pyrite, the most efficient metallic sulphide in the redeposition of ores. Sulphur, oxidizing to sulphuric acid (SO_3), requires less than one-fifth the oxygen that combines with an equal weight of hydrogen in forming water.

For illustration, the relative reducing power of hydrogen, carbon and sulphur may be compared with the heat generated by their combustion, although their calorific values do not run parallel with their respective powers in the deoxidation of mineral solutions.

A calory being the quantity of heat necessary to raise 1 lb. avoirdupois of water 1° C., the heat generated by the combustion of 1 lb. of the following substances is:

	Calories.
Hydrogen, ...	34,462
Carbon, ...	8,140
Bituminous coal, ...	8,750 to 7,800
Lignite, ...	7,300 to 4,600
Sulphur, ...	2,250

On account of the calorific value of the contained hydrogen, the heating-power of the highest grade of bituminous coals is greater than that of pure carbon.

It is not improbable that the bituminous coals occurring in association with the ore-deposits of the Southwest, on account of their purity and high percentage of hydrogen, have a some-

what greater reducing power than pure carbon, and are exceeded in power and intensity of action only by bitumen. The lignitic or finely divided coaly matter, disseminated in the black clays and shales, may be regarded for the purpose of this discussion as a form of highly impure bituminous coal. Anthracite may be classed with the bituminous coals, as it contains from 1 to 3 per cent. of hydrogen and 1 to 3.5 per cent. of oxygen.

The hydrocarbons may be divided into the petroleums, or fluid non-oxygenated compounds of carbon and hydrogen; the bitumens and asphalts, solid oxidized hydrocarbons, soluble in chloroform or other solvents of the resins; and the pyro-bitumens, which also contain oxygen and nitrogen, including anthracite, bituminous coal, lignite, etc.

The Oxygenation of Petroleum.

Experiments made by the author on the oxidation of petroleum show that the heavy hydrocarbon oils unite very slowly with oxygen, when first exposed to its action, even at temperatures as high as 150° C.; but after the action is once started, by the combination of even a little oxygen with the hydrocarbon, the further oxidation then proceeds with constantly increasing energy. By aspirating a current of air for ten days through heavy petroleum oil, at 140° to 155° C., there were formed solid hydrocarbons, resembling certain natural asphalts. Very little water was formed; the oil "cracking" and the hydrogen being removed in the form of light naphthas and non-condensable gases, containing a greater percentage of hydrogen than the original oil, and leaving oxidized hydrocarbons, with less hydrogen and a greater proportion of carbon.* The asphalts made in the above experiments absorbed oxygen from the air at ordinary temperatures; the rapidity of the absorption being increased if the asphalt was in a fine powder. Dana refers to these results as the manufacture of grahamite from petroleum.†

The oxides of lead, zinc and manganese, and certain salts of

* "On the Formation of Solid Oxidized Hydrocarbons Resembling Natural Asphalts by the Action of Air on Refined Petroleum," by W. P. Jenney, *American Chemist*, vol. v. (April, 1875), pp. 359–362.

† *System of Mineralogy*, edition of 1898, p. 1020.

the metals, notably manganese-borate, are powerful driers of the vegetable oils, such as linseed oil. Even in solution, many salts of the metals have a drying action if agitated with the oil. In the case of the vegetable oils, these metallic oxides and salts appear to exert a catalytic action in accelerating the combination of oxygen with the hydrocarbon.*

Experiments by the writer indicate that oxides of lead and manganese have a similar action in promoting the union of oxygen with petroleum; and that the asphalts produced retain 2 per cent. or more of lead-oxide, even after treatment with boiling acetic acid and purification by solution in chloroform or ether.†

From this point of view, it is probable that the oxidation of bitumen, in effecting the re-formation of the sulphides, is accelerated, and the intensity of the reducing action increased, by the catalytic influence of ferrous and ferric sulphates and by the various sulphates, carbonates, chlorides and oxides of lead, zinc, copper and manganese, which are always present in greater or less amount in the ore-deposits. With petroleum having a paraffin base, the union with oxygen would be extremely slow, were not the chemical activity stimulated in some way. Petroleum with an asphalt base, owing to the heavy hydrocarbons in the oil being combined with oxygen, and approaching fluid bitumen or maltha in composition, would probably absorb oxygen more rapidly.

That the natural asphalts and bitumens, when wet, are more subject to the action of oxygen than when dry, has been observed in the wear of asphalt pavements, which rapidly disintegrate in spots where surface-water accumulates.

The Chemical Reactions that Take Place.

In the reduction of metallic sulphates to sulphides, by carbon, the action in each case is deoxidation, with formation of carbonic acid, according to the following reactions:

$$ZnSO_4 + 2H_2O + 2C = ZnS + 2H_2CO_3.$$

$$PbSO_4 + 2H_2O + 2C = PbS + 2H_2CO_3.$$

* Catalytic action is understood to be the action of a substance which, by its presence, accelerates or retards the chemical activity, and may induce a chemical reaction that would otherwise not occur, or would take place only with extreme slowness.

† *Op. cit.*, pp. 359–362.

The complete reduction of ferrous sulphate to pyrite or to marcasite requires that free sulphuric acid be present:

$$2FeSO_4 + 2H_2SO_4 + 5H_2O + 7C = 2FeS_2 + 7H_2CO_3.$$

The carbonates of lead, zinc and iron, in the presence of alkaline sulphates, are reduced by carbon to the corresponding sulphides, galena, blende and pyrite:

$$PbCO_3 + Na_2SO_4 + 2H_2O + 2C = PbS + Na_2CO_3 + 2H_2CO_3.$$

$$ZnCO_3 + CaSO_4 + 2H_2O + 2C = ZnS + CaCO_3 + 2H_2CO_3.$$

$$2FeCO_3 + 4CaSO_4 + 5H_2O + 7C = 2FeS_2 + 4CaCO_3 + 5H_2CO_3.$$

Chalcopyrite, $CuFeS_2$, is formed by the double reduction of cupric sulphate and ferrous sulphate:

$$CuSO_4 + FeSO_4 + 4H_2O + 4C = CuFeS_2 + 4H_2CO_3.$$

The reactions which take place where the hydrocarbons form the reducing agents are more complex. The hydrocarbons at first lose hydrogen and gain oxygen, until disintegration occurs; then they rapidly oxidize to carbonic acid and water. With bitumen and coal, it is probable that practically all the carbon is finally converted into carbonic acid, and the hydrogen into water. In the oxidation of petroleum some "cracking" may occur, and a portion of the hydrogen and carbon may escape in the form of light hydrocarbon gases, as did take place in the experiments described above.*

Oxygen seems to be needed to complete the reaction in the reduction by petroleum of the paraffin series:

$$12ZnSO_4 + C_{16}H_{34} + O = 12ZnS + 16H_2CO_3 + H_2O.$$

Where the petroleum is partly oxidized, ferric sulphate forms pyrite in the presence of an excess of free sulphuric acid. The reaction may be written as follows:

$$3Fe_2(SO_4)_3 + 3H_2SO_4 + C_{16}H_{30}O_2 = 6FeS_2 + 16H_2CO_3 + 2H_2O.$$

To illustrate the partial reduction of ferric sulphate to pyrite,

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* See p. 448.

with formation of ferrous sulphate, the formula of an oxidized hydrocarbon nearly corresponding to humus acid is assumed, as in the following equation:

$$4Fe_2(SO_4)_3 + 8H_2O + C_{16}H_{16}O_8 = 4FeS_2 + 4FeSO_4 + 16H_2CO_3.$$

The complete reduction of ferrous sulphate to pyrite or to marcasite by an oxygenated hydrocarbon, such as gilsonite, $C_{13}\,H_{20}O$, also requires the presence of free sulphuric acid:

$$5FeSO_4 + C_{13}H_{20}O + 5H_2SO_4 + 3H_2O = 5FeS_2 + 13H_2CO_3 + 5H_2O.$$

II. Protective Action of Carbon and of Hydrocarbons.

Hydrogen and carbon have affinities for oxygen stronger than those of any other chemical elements, under conditions normally occurring in ore-bodies. By consuming the free oxygen in the circulating-waters, they act to preserve and shield from decomposition all metallic sulphides. Otherwise stated, all forms of carbon, and of the fluid and the solid hydrocarbons, when present in excess, owing to their superior affinity for oxygen, prevent the oxidation of the ores; although many of the minerals in the ore-bodies under other conditions, where carbon and its compounds are absent, or present only in a subordinate degree, are powerful deoxidizing agents.

In the mines at Joplin, Mo., the metallic sulphide-ores, blende and galena, and the associated minerals, chalcopyrite, pyrite, and even marcasite, are protected from decomposition below ground-water level by the bitumen and the bituminous shale contained in the wall-rock and present in the ore-bodies. Near water-level, on the boundary between the zones of oxidation and reduction, these hydrocarbons are consumed in places; although, a few feet distant in the same ore-body, they may occur in great excess. In such places the metallic sulphides undergo oxidation, only to be re-formed anew on coming in contact with the hydrocarbon.

This protective action has long been understood with respect to the rocks which contain organic matter. In the black-band iron-ores, and in many bituminous shales, the iron occurs as the proto-carbonate (siderite), and is preserved from oxidation by

the hydrocarbon. In the outcrop, such rocks are bleached by weathering, and the iron is oxidized to limonite or hematite. That organic matter preserves the strata from oxidation is a fact familiar to persons engaged in collecting fossils, particularly fossil-plants. The beds of black and gray shales, where the iron occurs as carbonate or sulphide, are carefully searched, while bright-colored strata, in which the iron is peroxidized, are given only a slight examination.

III. Contributory Action of Carbonic Acid Gas.

In the formation of ore-deposits, carbonic acid gas may, under special conditions, displace and expel the air from the cavities, channels and interspaces in the rocks, and in this way, by mechanically excluding the air, materially aid the reduction and precipitation of the ores by the ordinary deoxidizing agents. Conditions also occur in the oxidation and re-formation of an ore-body, particularly at those points where the zones of oxidation and reduction merge one into the other, under which carbon dioxide would be an efficient auxiliary in the process of reduction.

The specific gravity of carbonic acid gas, compared with air as the standard, is 1.524. Its action in displacing air is not unlike that of water; a rise in the ground-water from any cause, as is often observed, drives out the air from all the openings in the ore-bodies and checks the oxidation of the minerals.

In the Parker mine, Wood River, Idaho, the country-rock is a lime shale, heavily charged with graphite. Above the permanent water-level all the seams and joints in the rock are filled with carbonic acid gas, produced by the oxidation of the carbon. Carbon dioxide is found in a zone reaching from ground-water level to within 100 ft. of the surface; in this zone it fills all the rock-openings as perfectly as water fills similar openings below.*

Sulphuretted hydrogen gas, which has a specific gravity of 1.19, may act in much the same manner in excluding the air, although in itself it is a strong precipitating and reducing agent.

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* See pages 459 and 460.

Natural gas, notwithstanding its low specific gravity (0.558), may be held under pressure in the strata in much the same way as it occurs sealed in the interspaces of the Trenton limestone of the Ohio and Indiana gas-field.

At the Silver-Islet mine, Lake Superior, pockets filled with hydrocarbon gas were struck in drifting on the vein on the 8th (440 ft. vertical depth) and 10th levels (610 ft. depth). The gas was held confined in the seams of the slate and in the openings in the vein under a water-pressure of from 440 to 600 ft., equal to a pressure of from 190 to 265 lbs. per square inch.*

Observations at many gas-wells show that the pressure greatly exceeds that which would be due to a water-column equal in height to the depth of the gas-producing strata. There is no record of any measurement of the gas-pressure at Silver-Islet.

IV. The Stability of Carbonic Acid and of Water.

Carbonic acid when combined with a base is a weak acid, readily displaced by a stronger, as sulphuric, hydrochloric or phosphoric acid, and also by sulphur and by many of the organic acids. But the molecule of carbonic acid is never broken up, is never separated into its component elements under conditions ordinarily subsisting in the earth's crust, at least not at the depths reached in the underground circulation of meteoric water.

Volcanic action alone, or an earth-temperature far above normal, furnishes the physical conditions in which carbon dioxide is dissociated, or the conditions that admit of its being reduced to the monoxide by carbon, or by other deoxidizing agents.

Carbonic acid is a permanent refuge of oxygen; once locked up in combination with carbon, oxygen remains inert for all time, in a condition of stable equilibrium, inactive, and chemically indifferent to all the complex changes taking place in the depths of the earth.† Even in ore-deposits undergoing oxida-

* "The Silver-Islet Mine and Its Present Development," by Francis A. Lowe, *Eng. and Min. Jour.*, vol. xxxiv., pp. 320–323. See, also, p. 486, this paper, "Silver-Islet Mine, Lake Superior" (author unknown, with Supplement No. 1, by W. M. Courtis), *Eng. and Min. Jour.*, vol. xxvi., p. 438.

† Carbonic acid gas contains: Carbon, 27.27 per cent.; oxygen, 72.73 per cent.

tion and re-formation, carbonic acid, once formed, is itself insusceptible to chemical change. Neither hydrogen, carbon, sulphur, or the most powerful deoxidizing metallic sulphides, can decompose it at ordinary temperatures. This immutability, however, is maintained only under the conditions subsisting in the depths of the strata, where life does not exist; the carbonic acid in the soil and in the atmosphere readily gives up its oxygen and carbon to plant-life.

Water almost equals carbonic acid in stability. It is true that water is decomposed by electrolysis and in many chemical reactions in the laboratory; yet, at temperatures approaching the normal, water is probably not dissociated, except in a very limited way, in any of the processes incidental to ore-formation.

In the complex chemical changes that take place in the oxidation and re-formation of ores, it is possible that water may be decomposed; but, quantitatively, such dissociation must be insignificant. Practically, water may be regarded as chemically stable under ordinary conditions and temperatures. The fact that, in the presence of the deep-circulating underground waters that contain no free oxygen, the complex sulphides forming the ore-bodies have been preserved unaltered for ages, is evidence that water is chemically inert to all the elements present in the depths of the strata.

Among minerals, many oxygen compounds, as, for example, quartz, corundum, cassiterite, rutile and zircon, resist decomposition, as do also the silica, the alumina and the other acid radicals in silicates, aluminates, borates, phosphates, titanates, tantalates, tungstates and chromates. Minerals containing oxides of the alkalies and the alkaline earths, while usually permanent, may have their oxygen displaced by sulphur and by the halogens, chlorine, bromine, iodine and fluorine. In the greater number of the refractory minerals and permanent oxygen-compounds, the chemical union of the elements with oxygen may probably date back to the primal origin of the earth.

Carbon and hydrogen alone, of all the elements, unite with oxygen under conditions now subsisting in ore-deposits, to form fixed compounds, that, sealed in the rocks, can endure to the end of time.

V. Occurrence of Carbon and the Carbon-Compounds.

Carbon occurs as graphite in the metamorphic rocks and in the gangue of certain mineral-veins. It is also found, practically free from hydrogen, as graphitic anthracite, and, in small quantities, as native charcoal. In all cases carbon is the residual element in the decomposition of the organic matter deposited in the original sediments; the hydrogen, oxygen, nitrogen and sulphur with which it may have been combined have been eliminated.

Far more commonly, carbon, when in association with mineral-deposits, is combined with hydrogen and oxygen, usually in the form of bituminous coal or bitumen in the wall-rocks, or filling the ore-bearing fissures; in some instances, as in the Joplin, Mo., mines, it is distributed generally throughout the ore-bodies. In most carbonaceous shales, in the mining regions, the organic matter is mainly in the form of finely disseminated bituminous coal.*

It is somewhat remarkable, considering the almost universal distribution of petroleum, that the non-oxygenated hydrocarbon oils are found so seldom, either in the ore-deposits or in the ore-bearing formations. In a few instances, marsh-gas and other similar hydrocarbons which are gases at ordinary temperatures and pressures have been found in association with mineral-deposits.

VI. The Occurrence of Carbon, Alone.

Graphite.

In the metamorphic area of the Black Hills of South Dakota many large, irregular deposits of pyrrhotite occur, associated with belts of graphitic shales. Masses of crystalline pyrrhotite are encased in soft, black, shaly gangue-rock, carrying a large percentage of graphite. As observed by the author, these graphitic shales appear to form a specially favorable gangue for pyrrhotite, associated with ores of nickel and copper, and also for pyrite and arsenopyrite.

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* An analysis of the Hudson-River slates (Lower Silurian) gave 5 per cent. of fixed carbon and 3 per cent. of volatile combustible matter, or nearly in the proportion of carbon, 62.5 per cent.; volatile, 37.5 per cent.; corresponding to the composition of the best gas-coals. "Classification of Coals," by Persifor Frazer, Jr., *Trans.*, vi., 448.

Pyrrhotite is mined in the vicinity of Deadwood, S. D., for flux in pyritic smelting. The mineral shows on assay an average value of $1.00 to $2.00 per ton in gold, with usually less than 0.25 per cent. of copper. Many of the deposits of pyrrhotite in the region lying easterly and northeasterly from Harney's Peak carry a small percentage of nickel and copper. Dr. Carpenter says that assays of the nickeliferous pyrrhotite from this region, made at the Dakota School of Mines, show an average of 1.5 per cent. nickel, though samples carrying 8 per cent. have been found.*

F. M. F. Cazin describes the occurrence, in the Vermont copper-mine, of deposits of the sulphides of iron and copper in intimate association with graphite.†

Prof. J. F. Kemp notes that graphite, or some closely related carbon mineral, is not uncommon in the ore of the Mary mine, at Ducktown, Tenn. He says, "It must have been introduced as some gaseous or very mobile liquid hydrocarbon, which has penetrated into minute cavities and filled larger cracks, and has been subsequently changed to graphite."‡

Von Cotta, in his "Treatise on Ore-Deposits," cites many instances of the influence of carbon on the localization of ore-deposits. A single quotation is selected: "Near Freiberg the veins . . . are enclosed in mica schist which contains an irregular layer of black graphitic schist. . . . The veins have only been found productive in the black schist. In the common mica schist they are very poor."§

Silver Islet.—In the Silver-Islet mine, Lake Superior, graphite was found associated with native silver, silver-glance, tetrahedrite, argentiferous galena and a number of rare silver minerals, in a gangue of quartz, calcite and rhodochrosite. The geological formation is gray slate, nearly horizontal in bedding, traversed by steeply dipping, parallel dikes of diorite and other igneous rocks. The vein cuts vertically across the dikes and

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* "Ore-Deposits of the Black Hills of Dakota," by Franklin R. Carpenter, *Trans.*, xvii., 582.

† *Genesis of Ore-Deposits*, pp. 207–209; *Trans.*, xxiii., 605, 606. See, also, on this subject, "The Origin of the Gold-Bearing Quartz of the Bendigo Reefs, Australia," by T. A. Rickard, *Trans.*, xxii., 314, 315.

‡ "The Deposits of Copper-Ores at Ducktown, Tenn," by J. F. Kemp, *Trans.*, xxxi., 261.

§ *Treatise on Ore-Deposits*, Prime's Translation, pp. 46, 47.

the belts of slate included between them, but was ore-bearing only where it faulted the main dike of diorite. This dike, about 200 ft. in width, was in certain places strongly impregnated with graphite.* Intersecting fissures appear also to have had an influence on the localization of the ore. Two bonanzas were discovered: (1) The main ore-shoot (that produced over $2,000,000) extending from the surface to a depth of 330 ft., nearly to the 7th level, and formed at the intersection of a cross-vein with the main lode; (2) the rich body of native silver on the 3d and 4th levels, south (that yielded 800,000 oz. of silver), occurring near the junction of the two branches of the vein. Graphite was not found in the slates, or in any dike of the igneous belt intersected by the vein-fissure, with the exception of this particular dike, which in its limited outcrop above the surface of the lake, at the point where the lode cut through it, formed Silver Islet. The vein in no place carried workable ore-deposits, either in the slates or in the normal diorite. Before the mine was closed down, a small body of ore (that produced about $30,000) was struck on the 13th level, south. Like the larger ore-bodies in the upper-levels, the ore was found to occur in association with graphite. McDermott, writing of this mine, says: "The fact most striking, to one who examines the parts of the vein from which the most valuable ore has been extracted, is the evident connection of the deposit of the silver with the region of graphite impregnation of the wall-rock."†

Graphitic Anthracite.

An extensive deposit of graphitic anthracite, associated with antimonial silver-lead ores, was found in the Parker mine, in

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* "The trap-dike has usually been called diorite, but is determined to be norite by Wadsworth, *Bull.* No. 2, *Minn. Geol. Sur.*, p. 92, and gabbro by Irving, Monograph V., *U. S. Geol. Sur.*, pp. 378, 379." *Ore-Deposits of the U. S. and Canada*, by J. F. Kemp, p. 283.

† "The Silver-Islet Vein, Lake Superior," by Walter McDermott, *Eng. and Min. Jour.*, vol. xxiii., pp. 54, 55 and 70, 71.

"The Silver-Islet Mine and Its Present Development," by Francis A. Lowe, *Eng. and Min. Jour.*, vol. xxxiv., pp. 320–323.

"Silver Islet," by Thomas Macfarlane, *Trans.*, viii., 226–253.

"The North Shore of Lake Superior as a Mineral-Bearing District," by W. M. Courtis, *Trans.*, v., 473–487.

"Silver-Islet Mine, Lake Superior" (author unknown, with longitudinal section of the mine, Supplement No. 1, by W. M. Courtis), *Eng. and Min. Jour.*, vol. xxvi., p. 438.

Idaho. The vein occurred in a belt of graphitic lime-shales, about 600 ft. in width, included between two intrusive sheets of andesite; the whole formation—the vein and the igneous sheets bounding the shales above and below—dipping into the mountain at an angle of 40 degrees. The ores were galena and polybasite, averaging (in car-lots) from 75 per cent. of lead and 125 ounces of silver to 45 per cent. of lead and 680 ounces of silver per ton. The gangue was an intimate mixture of white crystalline calcite and quartz. An intersecting vein, coming in from the foot-wall, carried crystallized pyrite and blende, with only traces of silver. The mine produced $365,000. At a vertical depth of 300 ft. from the surface a flat fissure was encountered, filled with graphitic anthracite with a little white quartz intermixed. It formed a flat sheet, 2 to 6 ft. in thickness, and was explored over an area 200 ft. square. The coal was heavily slickensided, crushed and compacted into a hard, granular mass. It was mined with difficulty with a pick, and often required blasting, owing to the stringers of quartz distributed through it. Analysis gave, excluding ash, 90 per cent. of fixed carbon and 10 per cent. of volatile matter, mostly water from the clay contained in the ash. Owing to admixture of quartz and earthy material from the walls, the ash varied from 10 per cent. to 50 per cent. This coal had evidently been formed by the destructive distillation of asphalt or petroleum, filling the fissure. The intrusion of the sheets of volcanic rock enclosed the shale stratum as if in a retort. There is evidence, in the large amount of graphite in these shales, that they were originally highly charged with bituminous matter. The hydrocarbons, first distilled by the heat accompanying the intrusion, were condensed and accumulated in the fissure as heavy petroleum or asphalt, and, by further action of heat, carbon was deposited, hydrocarbon oils being driven off in the same way as in the distillation of petroleum-tar in the manufacture of lubricating oils. Subsequently the deposit was crushed by faulting movements of the beds, and at a still later date the ore-deposits were formed in the intersecting vein-fissure. In places the ore lies against and extends into the coal. Natural gas was not encountered, though conditions were favorable for its formation, probably because the workings were near the surface. Heavy flows of carbonic acid gas were, however, fre-

quently encountered in the mine; and during occasional periods of low atmospheric pressure the outflow of gas from the seams and fissures in the country-rock was so much increased that the miners were often driven from parts of the mine that were not well ventilated.*

J. B. Farish notes that the seams in the limestones at Newman Hill, near Rico, Col., were filled with carbonic acid gas.†

Charcoal.

Native charcoal, or mineral-charcoal, as it is termed, is probably never pure carbon, yet the amount of hydrogen contained is so small that in the discussion of its reducing power it may be classed with graphite. Observation shows that charcoal, from its soft, porous structure, and from the great surface it exposes to chemical action, is one of the most energetic deoxidizing agents in the formation of ore-deposits.

Small pockets filled with charcoal were found at a depth of 800 ft. in the ore-chimney of the Bassick mine, near Silver Cliff, Colorado. This remarkable occurrence of charcoal in an eruptive formation is set forth in detail in the paper by L. R. Grabill.‡

In the discussion of this paper, the occurrence of charcoal in anthracite was described by C. A. Ashburner; and of charcoal in Oregon, formed by the carbonization of the leaves and twigs of plants in the layers of mud between successive overflows of lava, by Dr. R. W. Raymond.§

President Rothwell remarked: "Charcoal has also been found in the silver-bearing sandstones of Southern Utah. These sandstones are a simple sedimentary formation, and contain trunks of trees, some finely silicified. . . . I have also found there pieces of lignite, with the structure of the wood still quite evident. . . . Other portions of the carbonaceous matter have almost the character of charcoal; the carbon has not become hard, nor taken on the form of lignite. The woody

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* "Graphitic Anthracite in the Parker Mine. Wood River, Idaho," by W. P. Jenney, *School of Mines Quarterly* (1888–89), vol. x., pp. 313–315.

† "On the Ore-Deposits of Newman Hill, near Rico, Colorado," *Proceedings of the Colorado Scientific Society*, vol. iv., p. 153.

‡ "On the Peculiar Features of the Bassick Mine," by L. R. Grabill, *Trans.*, xi., 110–120.

§ *Ibid.*, p. 119.

fiber of ordinary charcoal can be traced in it very clearly. . . . In the silver-bearing portions of the beds, the charcoal, the lignite, or the silicified wood, as the case may be, is impregnated with chlorides or sulphides of silver, and is in many cases quite rich."*

The deposits of silver-ore in sandstone at Silver Reef, Utah, are mainly due to the reducing action of wood and plant remains, more or less perfectly altered to lignite, and are treated in more detail under that head.†

VII. The Occurrence of Carbon Combined with Hydrogen.

Bituminous Coal.

Blende and galena have been deposited in coal in the outlying basins of the Coal Measures, scattered along the broad, northern marginal belt of the Ozark Uplift.

Near the reservoir at Sedalia, Mo., a basin in the Second Magnesian Limestone carries a little coal of fair quality, in which dark brown crystalline blende occurs in small irregular bunches and in sheets filling both the vertical and horizontal seams and joints. The greater part of the blende is in sheets, $\frac{1}{2}$ to $1\frac{1}{2}$ in. thick, made up of agglomerated imperfect crystals, compressed or flattened between the layers of the coal. Some specimens show blende in thin parallel seams, not thicker than a sheet of paper and $\frac{1}{32}$ to $\frac{1}{16}$ in. apart, distributed regularly through the coal. About 2 tons of blende were mined at this locality.

In Morgan and Moniteau counties, Mo., in a number of places, blende and galena are found in similar deposits of coal. At Martin's coal-bank, near Versailles, Mo., the coal has evidently been disturbed since its deposition, and vertical seams in the coal, $\frac{1}{4}$ in. to 1 in. in width, are filled with sheets of crystalline blende and galena in a gangue of calcite and white tallow-clay. The strike of the lines of disturbance of the coal, prolonged 500 to 1000 feet southerly, crosses an extensive tract of old surface-workings in the Second Magnesian Limestone. The ground is thickly covered by shallow pits, dug in search of lead-ore. These deposits of lead were apparently formed

* *Ibid.*, pp. 117, 118.

† See pp. 462–467.

through the agency of the same system of fissures that introduced the ore in the coal.

Blende and galena were formerly mined at Simpson's coal-bank, in Moniteau county. The coal is a hard cannel, filling a basin in the Second Magnesian Limestone; the ores occur in seams, seldom more than an inch in thickness, in the joints of the coal. The ore incidentally obtained in mining the coal afforded an occasional shipment to the smelters.

Vanadium is found in a lignite coal in the province of Mendoza, Argentine Republic. The ashes of this coal carry vanadic acid, V_2O_5. It also occurs in anthracite mined near Yauli, Peru.*

Gold has been repeatedly reported in the ash of the Cretaceous coals of the West. H. M. Chance records that the coal of the Cambria Coal Co. near Newcastle, Wyoming, is said, by the chemist of the company, to carry gold.† Mr. H. Rives Ellis, of Salt Lake City, informs the writer that he obtained an average of 60 to 80 cents gold per ton of ash from the Pleasant Valley, Utah, and Kemmerer, Wyoming, coals. In this connection, the paper by G. A. Koenig and M. Stockder‡ is of interest, although the coal described appears to be more nearly an infusible hydrocarbon, such as might result from the partial oxygenation of albertite.

Mr. Henry Sewell describes the occurrence of antimonial silver-ores, in association with strata, carrying beds of bituminous coal, in the mineral caves of Huallanca, Peru, located at an elevation of 14,700 ft. above the sea. These silver-mines are situated in a coal-formation, upturned on edge by an outburst of porphyry, the upheaval forming immense backbones, with the stratification standing almost perpendicular. A bed of coal is mined for blacksmithing purposes within a distance of 150 yards of the ore-bearing beds. The ore is tetrahedrite, with about 800 ounces of silver per ton, and occurs lining cav-

* 21*st Annual Report of U. S. Geol. Sur.*, 1899–1900, Part VI.; *Mineral Resources of the U. S.*, p. 315.

† "The Discovery of New Gold Districts," by H. M. Chance, *Trans.*, xxix., 227.

‡ "On the Occurrence of Lustrous Coal with Native Silver in a Vein in Porphyry, in Ouray County, Colo.," *Trans.*, ix., 650. See, also, "Modes of Occurrence of Pyrite in Bituminous Coal," by Amos T. Brown, *Trans.*, xvi., 539–546.

erns, in beds of sandstone. Some of these caverns are 25 to 30 ft. long and of nearly equal height, their inner surfaces covered with a coating 2 to 3 in. thick of crystallized silver-ores, mostly tetrahedrite. Silver-ores also occur in the shale beds adjacent to the sandstone.*

Lignite.

At Silver Reef, Utah, silver has been deposited in lignitic-sandstones, determined by Newberry to be of Triassic age.† The mines since 1885 have only been worked by leasers in a small way. During the height of production in 1877–79, the total output was 2,122,471 ounces of silver.‡ The ore-bearing beds were 30 to 40 ft. in thickness, of which usually only 16 ft. was pay-ore. The ore occurred in flat shoots that were, in some places, 300 ft. wide, and extended 400 to 500 ft. deep on the dip of the formation. The ore was richest near the outcrop, and, as it was followed in depth, gradually got poor. Near the surface the silver was in the form of chloride, associated in places with the blue and green carbonates of copper in very small quantity. As the ore was followed in depth, the chloride gave place to silver-sulphide, and scales of native silver came in, especially in the branches of trees and distributed in the plant-shales. No other ores were found, and the gangue-minerals usually occurring in ore-deposits, as quartz, calcite, barite, etc., were absent. When, following the inclination of the strata, the workings attained a vertical depth of 400 to 500 ft., the ore changed, becoming low-grade and difficult to amalgamate in pans; the ore-shoots at the same time contracted, becoming narrow, and only 2 or 3 ft. in height. Exploration was continued for several years, but finally all search in depth for pay-ore was abandoned.§

* "The Silver Caves of Peru," by Henry Sewell, *Eng. and Min. Jour.*, vol. xxiv., p. 292. Abstract taken from the *London Mining Journal.*

† "Report on the Properties of the Stormont Silver-Mining Company at Silver Reef, Utah," by J. S. Newberry, *Eng. and Min. Jour.*, vol. xxx., p. 269. See, also, "The Silver Reef Sandstones," by J. S. Newberry, *Eng. and Min. Jour.*, vol. xxxi., p. 4.

‡ *Eng. and Min. Jour.*, vol. xxix., p. 26.

§ "Silver Reef District, Southern Utah" (author unknown), *Eng. and Min. Jour.*, vol. xxix., pp. 25–26, 45–46, 59–60, 79–80, and 96.

"The Silver Sandstone District of Utah," by C. M. Rolker, *Trans.*, ix., 21.

"The Peculiar Features of the Bassick Mine;" Discussion by R. P. Rothwell, *Trans.*, xi., 117–119. *Genesis of Ore-Deposits*, pp. 130, 131.

Many writers report that traces of silver and copper occur in the extension of these same sandstone reefs, which can be traced by their outcrop for a distance of 10 to 20 miles to the southwest. An unknown author, in the early development of the district (May, 1877), thus describes the peculiar occurrence of the ore: "The formation is a beautifully stratified red and white sandstone, but greatly broken up and eroded. Where the strata have been undisturbed they rise to a height of perhaps a thousand feet above the adjacent valley, in table-mountains, alternately banded in red and white, and plainly showing the former height of the whole country. The numerous extinct volcanoes and the vast quantities of volcanic rock found throughout southern Utah, and particularly this section, point to at least one agent, and, no doubt, a powerful one, which served to produce the numerous foldings and contortions of the strata, while the great sandy deserts, covered with sage and cactus, bear abundant evidence to the erosion. On the northern side of what was once a vast basin, lying between several ranges of high mountains of old rock, where the erosion of an anticlinal has left ridges of reefs cropping out at various angles, are situated the mines. . . . The sandstone consists of red and white deposits, carrying some lime as a cementing material, with occasional layers of clayey or shaly rock, and considerable carbon scattered throughout. This carbon, which is evidently from the decomposition of drift material, of which the impression in the rock and even the *plant itself* is yet distinct, occurs in important layers in places. . . . Petrifactions, even of the size of large trees, are not uncommon, some of which form a valuable ore. The white sandstone, which appears to be of a somewhat finer texture than the red, seems, so far, to have carried the ore. . . . These veins, as they are there called, are entirely conformable with the strata, and in no case do they cut across the adjacent layers of rock. They appear to be richest where there is the most carbon, which evidently has acted as a reagent to precipitate the silver from solution and to deposit it, sometimes as flakes of metallic silver, in its midst. In some cases the form of the plant, of apparently a reedy nature, is yet distinct, in which the cells are yet visible, but to a great extent filled with valuable ore. Other beds carry considerable copper in the form of blue or green

carbonate, and also iron in nodules which run very high in silver. . . . A light sandstone, containing streaks or fine layers of a dark material, which elsewhere would not attract attention, is there found, sometimes, to run from $50 to $100 a ton; while the darker rock, containing considerable carbon, copper, or iron-nodules, will at times run into the hundreds, or even thousands."*

Mr. Watson M. Nesbit, who was connected with mining operations at Silver Reef from 1878 to 1888, gives the author the following statement of the manner of occurrence of the ore: In the Barbee and Walker mine, water was struck at a depth of about 500 ft. vertically. Near that point the ore changed in appearance and character, and gave great trouble in amalgamation, the extraction being very low. The ore was treated hot, in pans; a thick scum rose on the pans, like heavy petroleum oil, and had to be removed from time to time during the amalgamation. From a charge of 1½ tons of ore, as much as a gallon of this oily material would be obtained. The ore at water-level, if carefully stoped, averaged 12 to 16 oz. of silver per ton; but only a part of the silver could be saved in pans. A very little pyrite appeared at water-level—the first seen in the mines. About 100 to 200 ft. above water-level, on the slope of the beds, the ore was in places very rich; and small bunches of lignite coal, 4 to 10 in. across, were found imbedded in the soft sandstone, with native silver deposited in thin scales on the joints of the coal. Most of the ore at this depth was silver-sulphide. At one place a tree-trunk, 18 in. in diameter, was found; the heart-wood was silicified and very hard, and carried 8 to 10 oz. of silver per ton. The sap-wood and bark, 3 to 6 in. in thickness, were altered to soft, crumbling lignite, full of silver-sulphide; it assayed 5000 oz. of silver per ton. The ores from the Silver Reef mines never showed any gold by assay; but in leaching the ore by the Russell process, the silver-sulphides produced contained a trace of gold.

Review of the Phenomena at Silver Reef.—Light is thrown on the change in the mineral character of the ore at water-level, and on the difficulty experienced in amalgamation, by the dis-

* "The Silver Sandstones of Utah," by C. F. A., Salt Lake City, *Eng. and Min. Jour.*, vol. xxiii., p. 317.

covery announced by Newberry* that the ores carried selenium, —the average of four analyses giving selenium, 0.23 per cent., and silver, 0.26 per cent. The selenium in one specimen amounted to 90 ounces per ton.

Whether the silver was deposited at the same time the sediments were laid down, or was introduced by solutions upflowing through faulting-fissures in a later geological age, has been a much debated question. Without dwelling upon this point, —for, in either event, the primary deposition of the ore was due to the hydrogen and carbon of the plant-remains enclosed in the sandstones,—certain peculiar features of the occurrence deserve notice. The structure at Silver Reef may be stated as a broad anticlinal arch, broken up by faults coursing northerly and southerly, rudely parallel to the axis of the fold. A basin, nearly 3 miles across, occupied by the valley of the Virgin river, was eroded through the crest of the arch, leaving the two cliffs facing one another, the strata dipping away from the basin on the two sides. The total area of the several ore-producing belts of sandstone-outcrop, left by erosion, covered less than 500 acres.

Silver Reef conforms to the general law of areal distribution of mining-districts, namely, that "*Ore-deposits have been formed only in local areas of disturbance. Between and surrounding such areas of mineralization extend broad, barren tracts of undisturbed strata,*"† and also conforms to the law of mineral occurrence, namely, that "*All workable deposits of ore occur in direct association with faulting-fissures traversing the strata, and with zones or beds of crushed and brecciated rock, produced by movements of disturbance. The undisturbed rocks are everywhere barren of ore.*"‡ The descriptions apply to a mineral area which, prior to the recent erosion of the basin, may have possibly covered four or five square miles, with pay-ore found in no place outside this special area.

A writer notes that only the fractured, jointed and permeable portions of the bed are rich; where undisturbed and massive, the sandstone is barren. Also that vertical fault-

* "The Silver Reef Sandstones," by J. S. Newberry, *Eng. and Min. Jour.*, vol. xxxi., p. 5.

† "Lead- and Zinc-Deposits of the Mississippi Valley," by W. P. Jenney, *Trans.*, xxii., 192. ‡ *Ibid.*, p. 184.

planes frequently bound the ore.* These are conditions that are found in impregnated beds of zinc- and lead-ores in Southwest Missouri and Northern Arkansas, and also in the flat deposits of gold, associated with tellurium, in the Cambrian sandstone near Deadwood, South Dakota.

Selenium usually occurs with minerals believed to have been formed by highly-heated vapors and solutions and in direct association with igneous disturbances. Its presence at Silver Reef seems to favor the theory of the deposition of the silver through the fissures. It appears that secondary enrichment has taken place on an extensive scale, and that the silver was deposited originally in the sandstone in combination with selenium and probably with sulphur by the reducing action of the lignitic matter. Afterwards, these primary ore-bodies were enriched by the secondary precipitation of silver-sulphides, by the agency of descending surface-waters, aided greatly by the progressive erosion of the basin. In this migration of the ore—the outcrop of the sandstone gradually disintegrating and wearing away from exposure to weather—to the deposits of silver-sulphides, re-formed at deeper levels on the dip of the same beds, the reducing agent has been the organic material distributed through the ore-horizon. Later, these reinforced ores were, near the outcrop, altered to silver-chloride, cerargyrite, the trace of copper occurring with the silver forming the carbonates, azurite and malachite. When the mine-workings passed below this zone of enrichment there were found only small bodies of ore, that had remained unaltered since the first deposition of silver in the beds.

Similar occurrences have been described of copper-ores replacing the wood of trunks and branches of trees, and encrusting the leaves and stems of fossil-plants, in the Triassic sandstones of New Mexico,† and in the Permian sandstones of Russia.‡

E. J. Schmitz writes of the occurrence of copper-ores as

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* "Silver Reef District, Southern Utah," by R. P. Rothwell or Thomas Couch (?), *Eng. and Min. Jour.*, vol. xxix., pp. 25–26.

† "The Origin of Copper- and Silver-Ores in Triassic Sand-Rock," by F. M. F. Cazin, *Eng. and Min. Jour.*, vol. xxx., p. 381. "The Silver Reef Sandstones," by J. S. Newberry, *Eng. and Min. Jour.*, vol. xxxi., pp. 4–5.

‡ *Trans.*, ix., p. 33.

pseudomorphic replacement of wood and branches of trees in bituminous clay-slate in the Permian of Texas.* In the discussion of this paper, Mr. Henry Louis describes deposits somewhat analogous in the Permian of Nova Scotia, at New Annan, where the ore occurs in nodules of chalcopyrite, chalcocite, and iron-pyrites,† associated with plant-remains converted into anthracite.

Posepny also describes remarkable specimens of tree-trunks altered to galena from the Vesuvius mine, Freihung, Bavaria.‡

Bituminous Shales.

Rich deposits of blende, formed in great part by the secondary enrichment of smaller, or less mineralized, primary ore-bodies, are found near the surface in the Joplin, Mo., district, in the vicinity of Carthage, Lehigh, Central City and Reding's Mill. At these localities the ore occurs in two ways: in the beds of soft, decomposed carbonaceous shales in the Coal Measures, occupying shallow basins in the Subcarboniferous limestone of the region; or, more commonly, in horizontal channels eroded in the underlying limestone and filled with soft, dark mud, intermixed with bituminous matter, derived from these same shales, crushed by faulting movements and washed into the openings by surface-waters. Without regard to the character of the enclosing formation, these forms of ore-deposit are known to the miners as "mud-runs." These occurrences are seldom far from the surface; the deepest "run" of this character observed, near Reding's Mill, was at a depth of 90 ft. At Lehigh, similar deposits were found in the bottom-lands along the stream, within a few feet of the surface, where the permanent water-level came near to the top of the ground.

The ore occurs in minute crystals, thickly disseminated through the soft, shaly gangue, or enveloped in semi-fluid black mud. In some of the deposits the crystals of blende are agglomerated, forming irregular masses and sheets of pure ore. The crystals are of uniform size, usually from $\frac{1}{16}$ to $\frac{1}{8}$ of an in.

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* "Copper-Ores in the Permian of Texas," by E. J. Schmitz, *Trans.*, xxvi., 101.

† "Copper-Ores in the Permian of Texas;" Discussion by Henry Louis, *Trans.*, xxvi., 1051, 1052.

‡ *Genesis of Ore-Deposits*, pp. 129, 130.

in diameter, transparent, resin-yellow in color, with a shade of red, resembling in appearance the small garnets found in some placer gold-bearing gravels. The small size of the crystals is probably due to the concentration of the solutions from which they were deposited, and to their rapid formation. In some instances blende forms crystals in these shaly beds from $\frac{1}{2}$ in. to more than an inch in diameter, presumably from a slower and more prolonged growth. In all the deposits of this type, the reducing agent has been bituminous matter acting upon surface-waters, which carried in solution the sulphates of the metals leached from ore-bodies at higher levels, that were undergoing oxidation. The following equation shows the character of the change:

$$ZnSO_4 + 2CH + H_2O + O = ZnS + 2H_2CO_3.$$

It has been observed that these shallow mud-runs usually occupy synclinal basins or troughs, and that surface-erosion has often removed a considerable depth of the ore-bearing formations from the immediate vicinity; the deposits being located where they have received the drainage from surrounding mineral-areas.

At the Britton mine, Central City, the ore occurs at a depth 40 to 50 ft. from the surface, in a broad, flat, compound-run, 75 to 150 ft. wide and 6 to 12 ft. high, developed on its course for a length of 550 ft., northerly and southerly.* The ore is granular, crystallized blende in a stratum of soft, black mud and broken chert. The particles of blende are less than $\frac{1}{16}$ in. in diameter, deep garnet-red in color, and, although thickly distributed in the mud, are not agglomerated. A number of similar deposits are developed in the vicinity.

Ore-deposits of this character are easily mined with pick and shovel; powder is only used to break up an occasional boulder in the ore-body. The ore requires very little crushing and readily concentrates, yielding from 12 to 20 per cent. of clean blende. The product is very pure, assaying from 62 to 64 per cent. of metallic zinc.

Reding's mine, about 4 miles southeast of Joplin, is situated

* For a definition of these forms of ore-deposits, see "The Lead- and Zinc-Deposits of the Mississippi Valley," by W. P. Jenney, *Trans.*, xxii., 189, 190.

in a shallow basin in a low range of hills, bordering the north side of the valley of Shoal creek. At the time of the examination, this mud-run was opened 75 ft. in length, north and south, with a width of 36 ft., and a height of 12 to 18 ft. The ore occurs in dark-brown mud, in finely disseminated crystals, and in crystallized masses and sheets of galena and blende. Beautiful specimens of galena are found in very perfect cubical crystals, 1 to 2 in. on a side. The upper part of the run is mostly crystallized galena, while the lower part is blende, with a smaller proportion of galena. Boulders of flint and black clay-shales are found in the ore, together with much coarsely crystalline rotten dolomite.

This ore-deposit is remarkable for its extreme richness. To the date of my examination, the yield of the mine, estimated upon all material extracted, had been 15 to 20 per cent. of clean ore. When first formed, it was evidently a small run of blende and galena in dolomite; subsequently, surface-waters eroded a cavern-like channel following the course of the run. Material washed from the surface formations of broken and crushed bituminous shale filled this channel and enveloped the ore-body. Finally, the ore primarily deposited was greatly reinforced by secondary deposition, both galena and blende being crystallized in the fluid mud by the reducing action of the hydrocarbon.

A small basin of coal-shales, near Belleville, Jasper county, Mo., carried beautifully preserved fossil-plants. The outer surface of the mass of shales, for a depth of about a foot, contained scattered crystals of blende, from $\frac{1}{4}$ to $\frac{3}{4}$ in. in diameter, mingled with a few crystals of galena and pyrite. The central portion did not carry any mineral, the mass having been mineralized from the outside, toward the interior, as far only as the mineral-bearing waters could penetrate the dense plastic clay. The crystals, in their growth, have distorted otherwise perfect fossil-plants, crowding parts of the fern-fronds to one side; giving evidence that the deposition of the minerals was of later date than the preservation of the plant-remains. These plants were determined by David White to belong to a horizon near the middle, or the upper part, of the Lower Coal-Measures.*

* "Flora of the Outlying Carboniferous Basins of Southwestern Missouri," *Bulletin of U. S. Geol. Sur.*, No. 98.

On the Mine La Motte grant, in Southeast Missouri, deposits of disseminated galena in black shale of Cambrian age outcrop at the surface, and were worked for lead during the early period of mining in that region. The galena occurs in crystalline nodules, from $\frac{1}{4}$ to $\frac{3}{4}$ in. in diameter, thickly distributed in bands through the shale. This shale-bed appears to be a local formation. The ore-deposits closely resemble in mode of occurrence those of disseminated lead in the Cambrian limestone in the belt extending from Mine La Motte, through the Flat River district, to Bonne Terre.

The secondary formation of metallic sulphides is now taking place in the Missouri mines; blende and galena, oxidizing to sulphates in the ore-deposits near the surface, are carried in solution by the subaërial waters to the deeper horizons, and there regenerated by the deoxidizing action of bituminous matter. The subject is too extensive to admit of discussion here, and must be left for a future paper.

A single instance, however, may be cited of the reproduction of blende from mine-waters. An old tunnel, driven through bituminous shale on the Banker's Tract, near Joplin, became filled with water draining from adjoining mines on which work had been suspended. The tunnel remained closed and submerged for ten or twelve years, until the mines were unwatered in 1898. When reopened, the surface of the shales, on the roof and sides of the tunnel, was found to be thickly encrusted with minute crystals of blende, one- or two-hundredths of an inch in diameter. In places, the blende was deposited on the pick-marks made when the tunnel was run.

The paper of T. A. Rickard, on "The Enterprise Mine, Rico, Colorado,"* shows the existence of a strongly-marked resemblance between the occurrence of the flat ore-deposits at Rico, carrying silver and gold, and the ore-formation of Southwest Missouri, where galena and blende occur in simple runs, and also in compound runs, formed in like manner, in the favorable beds, by mineral-depositing solutions introduced through vertical fissures from an unknown source in depth, and where bituminous matter, contained in the ore-bearing strata, has likewise been the precipitating agent in the deposition of the ore.

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* *Trans.*, xxvi., 906–980.

Experiments made in the laboratory, to determine the reducing action of the black shale associated with the ore-bodies, are described by Rickard, as follows:

"A piece of the Rico shale was put into a weak solution of sulphate of silver (Ag_2SO_4) containing some free acid intended to neutralize the lime ($CaCO_3$) in the shale. The precipitation of metallic silver became visible in three days. The parallel experiment with gold was more interesting. A piece of ore (assaying 1147 oz. of gold per ton) obtained from . . . . Cripple Creek, was taken, and its gold was extracted by a solution containing ferric sulphate ($Fe_2O_3,3SO_3$), common salt ($NaCl$) and a little free acid (H_2SO_4). This Cripple Creek ore carried the black oxide of manganese (MnO_2) in visible quantity, and thus the chlorine used to form the gold-solution was liberated in a manner simulating natural conditions. Of the gold, ... 99.91 per cent. was extracted and subsequently precipitated on the Rico shale by inserting the latter in the solution thus formed. The gilding of the black shale by the deposit of gold became visible within four hours."*

W. Nicholas has made a series of similar experiments in the precipitation of gold by black carbonaceous shales from the Victorian quartz-reefs.†

The peculiar vein-formation known as the "Indicator" is an example of the localization of rich deposits of free gold, due to the reducing action of carbonaceous shales. Rickard defines the Indicator as "a very thin thread of black slate, which is remarkable on account of its extraordinary persistence, and also because the quartz seams which cross it are notably enriched at the point of intersection."‡ It is also referred to by Dr. Don.§ The Indicator is the most important member of a series of thin seams of black shale, more or less impregnated with pyrite and arsenopyrite, traversing the slate and sandstone formation of the district.

Different views have been expressed as to whether the car-

* *Ibid.*, pp. 978, 979.

† "The Origin of the Gold-Bearing Quartz of the Bendigo Reefs," by T. A. Rickard; Discussion, *Trans.*, xxii., 762–763.

"The Origin of Gold in Certain Victorian Quartz-Reefs," by William Nicholas, *Eng. and Min. Jour.*, vol. xxxvi., pp. 367, 368.

‡ "The Indicator Vein, Ballarat, Australia," *Trans.*, xxx., 1010.

§ "The Genesis of Certain Auriferous Lodes," *Trans.*, xxvii., 568–572.

bon or the pyrite in the Indicator seam was the reducing agent in the formation of the rich bunches of gold-ore. But pyrite was deposited in the black shale by the reducing action of the organic matter; so that, in any event, it was the presence of carbon compounds which, directly or indirectly, caused the local accumulation of the gold.

Owing to the far more powerful action of the hydrocarbons, reduction by pyrite contained in carbonaceous shales must always be subordinate, even where local conditions, such as the presence of free oxygen and oxidized metallic salts, admit of the pyrite being decomposed. Any ferrous sulphate produced, at once re-forms pyrite, giving up its oxygen to the carbon. In the depths of the strata, below water-level, wherever any form of carbon is in excess, it absolutely protects the pyrite by consuming all the free oxygen.*

Many instances might be cited to illustrate the influence of the organic matter contained in bituminous shales upon the formation of ore-deposits.

A stratum of black shale in the Mono silver-mine, Dry Cañon, Utah, formed the hanging-wall of the rich ore-shoot, from which large masses of horn-silver and high-grade sulphide-ores were mined, carrying from 500 to 3000 oz. of silver per ton. It is reported that a carload of ore from this mine yielded over $55,000.

Emmons says: "Most famous, in view of the enormous values taken from them, are the rich silver-bodies of the Mollie Gibson and Smuggler mines of Aspen, Colo.; but, in their case, there is sufficient organic matter present to explain the reduction of the oxidized solutions to sulphides. They occur along a vertical fault, formed since the original mineralization of the district, and consist of great masses of polybasite and pink barite, which, in places, have been further reduced to native-silver. On one wall of the ore-body is the limestone, of which it is a replacement, and on the other a black bituminous shale."†

Rickard, discussing this subject, writes: "The idea of the

* This subject is discussed in more detail, under the sub-head, Protective Action of Carbon and of Hydrocarbons, *Ante*, p. 451.

† "The Secondary Enrichment of Ore-Deposits," *Trans.*, xxx., 195. See, also, *Genesis of Ore-Deposits*, pp. 450, 451.

precipitation of the ore through the agency of carbonaceous matter has been advanced in connection with ore-deposits in other regions. I may quote, as instances, the black Silurian slates of Bendigo, Victoria; the Devonian slates of Gympie, Queensland; the Jurassic slates of the 'Mother Lode' region in Calaveras and Amador counties, California; the black shale enclosing the gold-specimen ores of Farncomb Hill, Breckenridge, Summit county, Colorado; . . . and the celebrated Indicator series of Ballarat, Victoria."*

In this connection, reference is made to the well-known occurrence of copper-ores at Mansfeld, Prussia, in beds of bituminous slate and bituminous limestone. Certain of the lower limestone beds are fetid. These copper-bearing formations extend over a large district.† The ore contains so much bituminous matter that only a little brushwood is required in roasting the ores in piles.

Limestones Containing Organic Matter.

In mining-regions where the ores occur in limestone, it is observed that in most instances the largest and most productive mines are in belts or zones of crystalline limestones which are either exceptionally pure lime-carbonates or, more frequently, dolomites with only a small amount of insoluble matter. Such formations, peculiarly favorable for ore, are rocks easily crushed by movements of disturbance, readily permeated by circulating-waters, and, from their chemical composition, rapidly attacked by solutions carrying carbonic acid. Where situated at the surface, they are cavern-forming limestones. Further, it is noted that both the magnesian limestones and the pure lime-carbonates usually contain some form of organic matter which, though small in amount, appears to have strongly influenced the deposition of the minerals in the strata.

Otherwise stated, ore-deposits in limestone, irrespective of the nature of the minerals constituting the ores, conform to the general law of selective deposition, namely, that "*Some geological formations appear to be everywhere barren of ore; others occasionally carry small deposits, workable where the conditions are*

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* "The Enterprise Mine, Rico, Colorado," *Trans.*, xxvi., 978.

† Von Cotta, *Treatise on Ore-Deposits*, Prime's Translation, p. 164.

exceptionally favorable; but in each mining region certain strata are ore-bearing in a degree exceeding all other formations combined."*

Among the causes that have induced the concentration and deposition of the ores in special formations, prominence may rightly be given to the deoxidizing action of the bitumen, bituminous coal, lignite, or other form of carbonaceous matter disseminated in the rock.

In Southeastern Missouri, the lead-ore now mined is mostly from deposits of disseminated galena in the dark-colored magnesian limestone, rich in bituminous matter, of the Cambrian formation at Bonne Terre and the Flat River mines. Practically all the zinc-ore, and the greater proportion of the lead, produced in the Joplin region, in the southwest part of the State, is yielded by the Cherokee limestone, the upper division of the Subcarboniferous.† The Cherokee is a soft, crystalline, pure lime-carbonate, carrying bitumen. Its average composition, from a number of analyses, is as follows:

Lime,	55.00
Magnesia,	0.23
Alumina,	0.10
Protoxide of Iron,	0.05
Protoxide of Manganese,	0.02
Bitumen and insoluble,	1.00
Carbonic acid,	43.60
	100.00

In the Upper Mississippi lead-region the productive formation has been the Galena limestone, the upper member of the Trenton. It is a soft, crystalline dolomite; bituminous matter is present in relatively small amount, yet apparently more than sufficient to effect the precipitation of the metals and preserve the ores from oxidation below water-level. The deposits of blende in the mines near Mineral Point and Shullsburg, Wisconsin, occur in the underlying "Blue" limestone of the Trenton, and the ores are concentrated about the intersection of the mineral-bearing fissures with thin strata of brown shale, saturated with petroleum,—the "Oil-rock" of the miners.‡

* "The Lead- and Zinc-Deposits of the Mississippi Valley," by W. P. Jenney, *Trans.*, xxii., 187–188.

† "The Lead- and Zinc-Deposits of the Mississippi Valley," by W. P. Jenney, *Trans.*, xxii., 188.

‡ William P. Blake, Discussion of "The Lead- and Zinc-Deposits of the Mississippi Valley," *Trans.*, xxii., 631.

A summary review of the occurrence of zinc- and lead-ores in the Mississippi valley shows that the formation of the deposits has been due to solutions of normal temperature; and that the chief agent in the primary deposition, and in the secondary enrichment of the ores, has been the bituminous substances contained in the strata in which the deposits are found. The larger part of the minerals constituting the ores has been deposited either by crystallization or by crystalline growth in the lime-rock or dolomite of the walls, or has impregnated the beds of specially favored geological formations.

In the limestone-area at Tintic district, Utah, the productive mines occur in two distinct belts in the Carboniferous formation; one, extending through the central part of the district, of dark-colored, magnesian limestones; the other, traversing Godiva mountain, on the eastern border of the lime-area, formed by beds of gray limestone with only a trace of magnesia.

On the central belt are situated the Gemini, Bullion-Beck, Eureka Hill and Centennial Eureka mines; and farther south, also in magnesian limestones, are located the Grand Central and the Mammoth. A number of these mines have been worked continuously since the early development of the district in 1870–71. All have reached a depth of 1000 to 1750 ft.; the Mammoth is now 2100 ft. deep.

It is not necessary to discuss the occurrence of the ore, beyond its relation to the magnesian limestones in which the deposits are found. Locally, these limestones vary somewhat in character; they are hard, crystalline, bluish-gray to bluish-black dolomites, the color being due to organic matter. In certain places the beds are filled with nodules and thin bands of hard, black chert. The average composition, from 7 analyses, of the limestones in the vicinity of the Bullion-Beck mine is (the organic matter and loss being estimated by difference):

Calcium carbonate,	48.76
Magnesium carbonate,	35.43
Ferrous carbonate,	2.61
Silica,	9.67
Alumina,	3.00
Organic matter and loss,	0.53
	100.00

In a number of analyses the silica varied from 6.75 per cent.

to 13 per cent., and the total insoluble matter from 16 per cent. to 18 per cent.

The amount of silica and insoluble matter is remarkable, for there is every evidence in the mines that these dolomitic limestones are rapidly decomposed and eroded by carbonated waters. The explanation of this marked solubility of the dolomite, notwithstanding the large proportion of impurities, is probably to be sought in the structure of the rock. In the upper levels of the Bullion-Beck and the Eureka Hill mines, where the subterraneous erosion by surface-waters has been greatest, large masses of residual dolomite sand, which have resulted from the disintegration of the fissured and shattered beds, occur, filling cavern-spaces or chambers in the limestone. Beneath the heavy wash of boulders filling the gulch, the limestone beds, for a depth of near 100 ft., without change in the stratification, are decomposed and altered *in situ* into soft, sandy dolomite, stained with iron and manganese oxides. Analyses showed that this decomposed rock had substantially the same composition as the loose deposits of sand; being dolomite, with the residual silica, clay, oxidized iron and manganese contained in the original formation. Surface-waters, carrying carbonic acid, appear first to attack the calcareous cement between the crystalline grains of dolomite, at the same time oxidizing the carbonates of manganese and iron present, and in this way rapidly disintegrate the rock.

Many caverns, mostly of small size and usually more recent in formation than the ore-bodies, occur in the limestone. It is noted that they are generally located along the course of the vertical faulting-fissures, which have been the channels followed by the solutions depositing the ore, the shattering and brecciation of the beds, due to the faulting movement, increasing the action of surface-waters in the erosion of the rock.

In a few instances the ore actually fills pre-existing caverns. The largest of these caverns in the Bullion-Beck mine, formed before the minerals were introduced in the primary deposition, was filled with argentiferous galena, in great part deposited by crystallization. The rock-floor of the cavern was covered by a horizontal stratum of chert nodules, overlain by sand-beds, 10 to 15 ft. in thickness, with disseminated pyrite and galena, the

massive crystalline lead-ore resting on the sedimentary beds. The flat-beds covering the clay floor were unquestionably formed from the residual sand and chert contained in the rock, dissolved away by the circulating-waters in making the cavern. Such occurrences of ore deposited by crystallization are rare in these mines; practically all the quartz, and nearly all the lead- and copper-ores, are formed by replacement.

The limestones are much purer in the Grand Central and Mammoth mines. An average of 6 analyses gave (ferrous carbonate, alumina and organic matter not determined):

Calcium carbonate,	55.38
Magnesium carbonate,	42.84
Silica,	0.65
Undetermined and loss,	1.13
	100.00

This is a bluish-gray, brown, or bluish-black, crystalline dolomite, free from chert. The weathered outcrop of certain beds shows the rock to be made up of the broken and water-worn joints of minute crinoid stems, one- to three-hundredths of an inch in diameter, with fragments of shells and an occasional small coral. The stratification is generally preserved; in some places the rock is cross-sheeted by movements of disturbance, and locally the beds have been brecciated and recemented by their own attrition material into a massive rock, with but traces of bedded structure.

This limestone, even where not mineralized, is easily distinguished by the appearance and fracture of the rock,—being dark-colored and crystalline, with spots and small vugs of calcite and stains of iron and manganese oxides on the joints. It is often sonorous, giving a clear metallic ring when struck with a pick. It crumbles under a blow into small, ragged, rough fragments, having the fracture of loaf sugar.

The beds are thin, brittle, easily shattered and crushed by faulting-movements. On account of the absence of clay in the rock, the breccias and attrition-material produced are permeable to circulating-waters; even small fissures and fractures in the lime keep open. Caves of considerable size are not infrequently encountered in the formation, but appear to have been formed subsequent to the ore. It is noteworthy that deposits of loose

dolomite-sands are seldom formed in this pure dolomite; neither is the rock usually altered in place to iron-stained rotten dolomite. The action of surface-waters is to dissolve the rock completely, and not to disintegrate the rock by attacking the calcareous cement between the grains.

The ore-bodies afford evidence that this limestone, especially where fissured and fractured, is easily replaced by silica and by the other gangue-minerals, ankerite, siderite, barite and calcite. Not only has the limestone been metasomatically replaced by primary sulphide-ores, carrying lead, copper, iron, arsenic, silver and gold, but the complex products of their oxidation and redeposition have, also, more or less perfectly replaced the rock. It is observed that the darker and coarsely crystalline lime-beds are highly favorable for ore,—beds made up of comminuted fossil-remains, crinoid stems, broken corals and shells.

Eliminating the highly impure sediments, which seldom carry workable deposits, the structure of the rock appears to be far more important than the chemical composition in determining whether certain strata are ore-bearing or barren. Analyses of the magnesian limestones over a broad belt show that they vary but little in composition. The beds which have been found to be unfavorable for ore are usually dense, finely crystalline and impermeable; the rock generally breaking under a blow of a hammer with a "dead" sound, and a smooth, splintery fracture, like the fracture of quartzite. Organic matter is not at all prominent in this limestone, although it gives the color to the rock.

The principal ore-bearing formation in Godiva mountain is a stratum, 200 to 400 ft. in thickness, of massive, gray, very coarsely crystalline limestone. It is a pure lime-carbonate, carrying some undetermined form of bituminous material, which gives to the rock, when broken, a sulphurous, fetid odor. On dissolving the limestone in acid, the bitumen separates in clots. An analysis of this limestone gave (the organic matter and loss being estimated by difference):

Calcium carbonate,	98.75
Alumina and iron-oxides,	0.40
Silica,	0.20
Magnesia,	trace.
Organic matter and loss,	0.65
	100.00

The weathered outcrop of the gray limestone is, in many places, bluish-black from the concentration of the bitumen in the surface of the rock. The beds are formed of water-worn grains and broken fragments of small shells. A coral (zaphrentis), 1 to 2½ in. long, is its characteristic fossil. It exceeds in chemical solubility all other ore-bearing limestones in this section of the district. The perfect manner in which great masses of the rock are replaced by the ore is evidence of this.

The gray-limestone formation extends northerly and southerly through the whole length of Godiva mountain, bounded on either side by limestones more or less magnesian in character. Many of these magnesian limestones, interbedded in the series, are highly impure sediments, with 25 to 35 per cent. of silica, 5 to 10 per cent. of iron and alumina, 6 to 12 per cent. of magnesia, and 20 to 30 per cent. of lime. These formations have been found unfavorable for ore.

On this gray-lime belt are located the Uncle Sam, May-Day and Yankee Consolidated mines,—properties developed since 1897. The deepest workings have attained a depth of 800 ft. The Uncle Sam mine has been noted for its large output of high-grade lead-ore, carrying silver, in a gangue mainly composed of lime-carbonate.

Quartz-ores prevail in the other mines of the belt, with lead, silver, and usually a small amount of gold.

The ores have been introduced in the strata through belts of nearly vertical faulting-fissures. Along the course of these fissures the ore-bodies have formed in the limestone. In some places the ore-deposits take on the form of fissure-veins, the ore being confined within the walls of the fissure and deposited in a more or less tabular sheet, pitching like the ore-shoots in quartz-veins in the metamorphic rocks. More commonly the faulting movements forming the fissures have so fractured the beds that the mineral deposits are not limited by the fissure-walls and extend irregularly into the limestone. The largest ore-bodies have formed in spaces of multiple fissuring, where the belt of master-fissures cuts through lime-beds, broken and rifted in different directions by the complex intersection of sheeted belts, due to cross-fissures and to diagonal fissures.

The ores of primary formation are mostly deposited by replacement of the limestone. Quartz occurs in many varied

forms,—from massive limestone, more or less completely altered to quartz, with little change in structure, to the white, crystalline mineral, grading insensibly into soft, crumbling, pulverulent quartz, in appearance resembling granulated sugar.

In certain places in these mines the limestone appears to have been sheeted and broken into large, thin and sharp fragments before it was replaced by the ore; the sharp edges of the pieces of limestone were not rounded in the conversion; there has not been any solution of the rock without the perfect pseudomorphic replacement of its structure by the minerals.

This has occurred not only in the replacement of the limestone by quartz, but also in its replacement by massive argentiferous galena, as fine-grained in its crystalline structure as steel. The galena reproduces the shape of the original limestone fragments, so that they are fossilized by lead-sulphide, as wood is petrified by the infiltration of silica, only less perfectly.

The largest body of galena of this character occurred in the Uncle Sam mine. The ore-body, 50 ft. long, 13 to 20 ft. wide, and 50 to 60 ft. high, was formed entirely of pure lead-sulphide, with no other minerals except calcite and the lime wall-rock. The ore averaged 75 per cent. of lead and 50 oz. of silver per ton. In this ore-body the massive limestone, prior to its mineralization, had been fractured vertically in large, sheeted fragments, some of which would measure 10 to 15 ft. long and 10 to 25 ft. high, but only 6 to 15 in. thick. Even the largest masses of rock were altered throughout to steel-galena. Numerous vertical open seams and fractures, from the thickness of a knife-blade to 2 in. in width, separated these irregular sheets of ore one from another. A vertical fracture, 12 to 18 in. wide, passed through the ore-body; it was more recent in formation than the primary ore and was filled with coarsely crystalline galena, with cleavage faces 2 to 3 inches across, deposited by crystallization.

In general, in the mines on Godiva mountain, fine-grained galena, replacing the limestone, is of primary origin, while coarsely crystalline galena is usually secondary; although some of the lead-ore deposited by crystallization (or crustification) appears to be primary.

Review of the Phenomena of the Deposition of Ores in Limestone.—A study should be made of the structure of the ore-bearing limestones, with the special object of determining the causes that have made certain strata favorable for ore, while other beds in the same geological formation, having an almost identical chemical composition, and so situated that they are traversed by the same fissures, through which the mineral-depositing waters have been introduced, have remained barren. In many instances the productive and the barren strata are interbedded and so situated that the ore-bearing fissures cut through all the beds alike, without any change in this selective deposition of the ores.

Analyses of these ore-producing limestones are needed to determine the amount and character of the carbonaceous substances present, and also the minute traces of other elements, some of which may be found to have had an influence on the formation of the deposits. That such an influence may have been exerted seems probable, when we consider the enormous masses of the highly soluble limestones that have been dissolved or replaced in the creation of the ore-bodies. It has been shown, for example, that the small percentage of bitumen or other hydrocarbon contained in the rock, and set free by its dissolution, has strongly aided in the deposition of the ore.

Prof. Church, discussing the deposition of ores in limestone, says: "The operation of solutions whose composition we do not know can be judged only by their effects. When metasomatic replacement takes place in limestone, it is generally assumed that lime-carbonate goes into solution, while its place is taken by the ore-substances,—that is to say, that the action is molecular substitution, and not atomic; but it is conceivable that the change should begin by an interchange of acidic elements—that SiO_2 should drive out CO_2. Subsequent changes might remove the lime-silicate by another process of substitution, since it is more soluble than silica;* but the point is that CO_2 would be liberated, and, though the original ore-solution were free from CO_2, it would immediately become charged

* In the Tintic mines, lime-silicate does not appear to have been formed ; the silica directly replacing the lime-carbonate, or the carbonate of lime and magnesia, as the case may be.

with that agent and exert the well-known dissolving power of carbonic acid solutions. In this way a solution which would have but feeble power in other rocks may in limestone set up a chain of reactions that would intensify its effects. . . . Limestone contains the elements for self-destruction, since the breaking-up of one lime-carbonate molecule may cause the solution of another; and as this cannot be said of any other rock, we reach a possible explanation of the comparative frequency of ore-bodies in limestone. The dolomites would, of course, present similar reactions." Prof. Church continues, respecting "The selection of a favored stratum for ore-deposition. In some situations the solutions, before reaching the stratum of actual ore-deposition, must have passed several strata suitable for their action, if they had possessed from the beginning the power of solution which they showed ultimately. . . . Ore-solutions exhibit a selective power which is extraordinary in a water fully supplied with dissolving qualities, but quite explicable in a solution which lacks this power."*

Many contributory causes have in all probability co-operated in the deposition of the ore, such as decrease of pressure and reduction in the temperature of the solutions, the mingling of mineral-bearing waters of different chemical composition entering the limestone formation through distinct fissured belts, etc.; but the important factor appears to have been the great solubility of these limestones and dolomites in the waters which brought in the minerals, joined with the chemical activity of the contained hydrocarbons released in the dissolution of the rock.

In the solution of the limestone, the incidental liberation of large volumes of carbonic acid, ever dissolving more and more of the rock, set free a constantly renewed supply of carbonaceous matter, whose function was to remove all free oxygen and reduce the sulphates in the waters to sulphides. At the same time, the calcium- and magnesium-carbonates, when dissolved, neutralized the acids and destroyed the chemical equilibrium, so that the mineral-saturated waters could no longer hold the metals in solution, after the addition of the elements derived from the limestone. The combined action of

* *Genesis of Ore-Deposits*, pp. 196, 197. *Trans.*, vol. xxiii., 595, 596.

the carbon, hydrogen, lime and magnesia contained in the rock was to deoxidize the solutions and bring them to the "critical-point," when deposition of the ores rapidly took place.

In conclusion: The ores of primary formation in the Tintic mines have been, in most of the occurrences, deposited from highly heated solutions by the metasomatic replacement of the limestone; only in relatively subordinate amount have the metallic sulphides been formed by crystalline growth in the rock, or by crystallization in the interspaces of the ore-bodies.

In the instance cited, in the Uncle Sam mine,* in the large body of steel-galena, without quartz, replacing the fractured lime strata, the deposition seems to have been from solutions either free from silica, or more probably of so low a temperature that the chemical reaction in the substitution of quartz for the lime-carbonate could not take place.

In Tintic, the limestones, when unaltered, retain the included carbonaceous matter deposited with the sediments. In the ore-bodies, all forms of the hydrocarbons have been destroyed, either in the primary formation of the minerals or in the subsequent oxidation; the deepest mines in the district (1700 and 2100 ft., vertical depth) not having reached ground-water level.

Whatever may have been the *rôle* of the volatile hydrocarbons in the original creation of the deposits, no evidence has been found of their ever having been present. Tintic district has been a center of intense volcanic activity, and it seems almost inevitable that, with the presence of notable quantities of bituminous matter in the rocks, volatile hydrocarbons would have been formed.

Many examples might be given of limestones, especially of magnesian limestones, which carry more or less organic matter and constitute the favored geological formations in the selective deposition of the ore. The zinc- and lead-deposits of Missouri and the lead- and copper-ores of Tintic District, Utah, carrying silver and gold, were chosen, owing to the author's more detailed acquaintance with the ore-deposits of those regions.

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* See *ante*, p. 480.

Petroleum.

The occurrence of petroleum in the Redington quicksilver-mine, New Idria, California, is reported by Luther Wagoner.* He says: "Mineral-oil occurs in considerable quantity, a barrel of forty gallons being collected in one drift. It was used for lubrication of the machinery."

Prof. Egleston, writing of the quicksilver-mines in northern California, says: "At the Rattlesnake mine, near Pine Flat, where large quantities of metallic mercury are found, the rock contains so much petroleum that it has been necessary to make special arrangements to burn the carbides of hydrogen, since the distillation of the petroleum causes an extra quantity of poor soot to be formed in the condensation-chambers."†

At the zinc- and lead-mines near Shullsburg, Wisconsin, thin partings or beds of brown shale, highly charged with petroleum, are found in the Trenton limestone. Prof. Blake, discussing the peculiar occurrence of this shale, known as the "oil-rock," says: "We find that this petroleum-shale, this horizon of hydrocarbons, is to-day the chief lower horizon of deposition of the lead- and zinc-ores. Certainly, if this shale did not influence or determine the original primary accumulation of the ores, it appears to have exerted a very important influence upon the secondary or later deposition, from solutions percolating downwards."‡

In the mines at Silver Reef, Utah, an oily substance, supposed to be petroleum, is reported to have occurred in the refractory ores at water-level.§

Rudolf Keck notes the association of organic matter with ore-deposits. He says: "Organic matter occurs in the state of asphaltum in the cinnabar mines in the Bavarian Palatinate; in that of petroleum, in the mines of California, Nevada and Hungary; in that of anthracite and graphite, in mines in Transylvania, Portugal, Derbyshire, Calcutta, Saxony, Baden, etc."||

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* "The Geology of the Quicksilver-Mines of California," by Luther Wagoner, *Eng. and Min. Jour.*, vol. xxxiv., p. 334.

† "Notes on the Treatment of Mercury in North California," by T. Egleston, *Trans.*, iii., 273.

‡ William P. Blake, Discussion of the "Lead- and Zinc-Deposits of the Mississippi Valley," *Trans.*, xxii., 631.

§ See *ante*, pp. 462–466.

|| "The Genesis of Ore-Deposits," by Rudolf Keck, *Eng. and Min. Jour.*, vol. xxxv., p. 3.

Bitumen.

The occurrence of bitumen, and its influence in the formation of the zinc- and lead-deposits in the Cherokee limestone, in Southwest Missouri, has already been discussed.*

Becker notes the existence of bitumen in the Manhattan, Knoxville, Phœnix, Oathill, Manzanita, Great Western and Great Eastern quicksilver-mines, and also at Sulphur Bank, California. At the Phœnix mine, a peculiar non-oxygenated hydrocarbon (napalite), with 90 per cent. of carbon and 10 per cent. of hydrogen, occurs quite abundantly.†

Luther Wagoner, in an article on the geology of the quicksilver-mines of California, says: "Oil (petroleum), more or less oxidized, is observed in all mines of quicksilver on this coast, and in general is found as bitumen or a thick tar."‡

Prof. Christy thus describes the occurrence of bitumen at New Almaden, Cal.: "The ore at New Almaden is cinnabar. Native quicksilver occurs also; but, as a rule, in small quantities only. Pyrite occasionally accompanies the ore. Bitumen is quite common, sometimes as a fragile, black, lustrous solid, resembling soft bituminous coal, but melting easily, like tar; at other times it occurs in the vugs of the gangue, in a liquid state, like coal-tar. I have found lumps of apparently pure cinnabar from the New Almaden to give a voluminous residue of pulverulent charcoal, when subjected to sublimation out of contact with the air. This would seem to show that the bituminous substance is intimately associated with the cinnabar."§

Marsh-Gas (CH_4).

In the quicksilver-mines of California marsh-gas was discovered by Becker. In the Phœnix mine, on the 150- and 300-ft. levels, inflammable gas, mainly composed of marsh-gas, issues from cracks in the rock.|| At Sulphur Bank, California, 79

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* See *ante*, pp. 445, 446.

† "Geology of the Quicksilver-Deposits of the Pacific Slope," by Geo. F. Becker, *U. S. Geol. Surv.*, Monograph xiii., pp. 371, 372.

‡ "The Geology of the Quicksilver-Mines of California," by Luther Wagoner, *Eng. and Min. Jour.*, vol. xxxiv., p. 334.

§ "Quicksilver-Reduction at New Almaden," by Samuel B. Christy, *Trans.*, xiii., 547–548.

|| "Geology of the Quicksilver-Deposits of the Pacific Slope," by George F. Becker, p. 373.

parts of marsh-gas were found in 1000 parts of the gases escaping with the ore-depositing waters.*

Flows of gas under heavy pressure were struck in the deeper levels of the Silver-Islet mine, Lake Superior. Subsequently, in extending the levels, vugs and cavities in the vein were found, lined with crystals of galena and calcite, in which the gas had probably been stored. In sinking the shaft, gas was also encountered in the slate, and it appears to have pervaded the country-rock below the 8th level (440 ft., vertical depth). The gas was associated with small flows of strong, acrid mineral-water, carrying much calcium chloride. It burned with a purple, blue, or yellowish flame, and was supposed to be light carburetted hydrogen, but it was never analyzed.†

Small quantities of hydrocarbon-gas are stated by Mr. B. Tibbey to have been struck in following the vein on the 300-ft. level of the Illinois mine, Walkerville, Butte City, Montana. The gas burned with a bright-yellow flame, like ordinary illuminating gas. This occurrence is remarkable, as the vein occurs in granite.

Review of the Action of Volatile Hydrocarbons.—In the Joplin, Mo., mines, the greater part of the bitumen set free by the extensive subterraneous erosion of the lime strata is still preserved in the ore-bodies below water-level, owing to the primary deposition having been effected by mineral-solutions of normal temperature. The same is also true of the petroleum occurring with the zinc-ore in the oil-rock in the Trenton limestone in Wisconsin, to which reference has been made. But in many ore-deposits in other mining-regions the heat accompanying the deposition has been so great, and the chemical activities so intense, that every trace of volatile hydrocarbons has been destroyed.

Petroleum contained in the strata may be decomposed by (1) destructive distillation, due to the earth-temperatures or to the heat of the ascending mineral-solutions; (2) by oxidation, the carbon and hydrogen forming carbon-dioxide and water; and (3) by the action of sulphur, which dehydrogenizes the oil.

* *Ibid.*, p. 258.

† "The Silver-Islet Mine and Its Present Development," by Francis A. Lowe, *Eng. and Min. Jour.*, vol. xxxiv., pp. 320–323. See also *ante*, p. 453.

Petroleum and similar hydrocarbons, when heated and subjected to the action of sulphur at temperatures (in the case of the heavier oils) far below that at which distillation occurs, are rapidly decomposed, with formation of sulphuretted hydrogen and of oils with a greater proportion of carbon than the original oil; or, if the sulphur be in excess, carbon is in some instances deposited.

The *rôle* of the volatile hydrocarbons in the primary formation of mineral-deposits, especially where the deposition is due to igneous disturbances, has not received the attention it deserves. Investigation is needed of the action that marsh-gas and other hydrocarbon-gases exert in the deposition of ores; particularly in the formation of deposits of cinnabar, which are frequently associated with bituminous shale, bitumen and volatile hydrocarbons.

Marsh-gas has a theoretic reducing power one-half that of hydrogen and fifty per cent. greater than that of pure carbon. In the formation of ore-deposits, directly induced by igneous action, temperatures must inevitably occur in the depths of the strata, such that gaseous hydrocarbons would act with great energy in the deoxidation and precipitation of the metals. Under like conditions, petroleum, and the volatile carbon compounds with high boiling-points, would exert a reducing power but little inferior, and, from the high specific gravity of their vapor, would displace steam and all other gases of less relative weight.

VIII. The Relative Reducing Power of Minerals.

Calculation of the Theoretic Reducing Powers of Various Organic and Inorganic Mineral Substances usually Occurring in Association with Ore-Deposits, Based upon the Weight of Oxygen Consumed.

The quantitative value, or amount of work accomplished in the formation of ore-deposits by the various reducing substances, is measured by the weight of oxygen with which they unite. This work of deoxidation may be termed the "*duty*" of the reducing agent.

In calculating this duty for the more common organic and inorganic minerals which occur in ore-bodies or in strata in which ores were formed, or into which they were intro-

duced by the waters, either in the original deposition or in the secondary enrichment of the deposits, it has been found more convenient to make the values relative, assuming hydrogen, the most powerful deoxidizing agent, to have a value of 100.

Let R represent the relative reducing power, or duty, of any mineral substance.

Q be the weight of oxygen consumed by one part of the mineral.

S be the weight of the mineral required to unite with one part of oxygen.

P be the weight of hydrogen which combines with 100 parts of oxygen.

The value of Q may be determined in each case from the chemical reactions which take place.

Thus, for hydrogen,

$$2H + O = H_2O,$$
$$2 + 16 = 18,$$

whence, by proportion, the weight of oxygen consumed by 1 part of hydrogen is determined.

$$2 : 16 :: 1 : Q = 8.00.$$

R has been assumed for hydrogen as 100.

In the case of carbon, the reaction is

$$C + O_2 = CO_2,$$
$$12 + 32 = 44,$$

whence, $12 : 32 :: 1 : Q = 2.6666$.

The relative power, or duty, of carbon compared with hydrogen is

$$8 : 2.6666 :: 100 : R = 33.33.$$

For oxygen the value of P is determined from the weight of hydrogen that unites with one atom of oxygen:

$$O + 2H = H_2O,$$
$$16 : 2 :: 100 : P = 12.5.$$

P is a constant and always a minus quantity; the oxygen combined with a mineral substance diminishing its reducing power.

R, Q and S are determinable by the following formulas:

$$R = \frac{100\,Q}{8}, \qquad Q = \frac{8\,R}{100}, \qquad S = \frac{1}{Q};$$

whence, by substitution,

$$S = \frac{1}{Q} = \frac{1}{\frac{8\,R}{100}} = \frac{12.5}{R}, \qquad Q = \frac{1}{S}, \qquad R = \frac{12.5}{S}.$$

From the above it is seen that in assuming, for convenience, the value of R for hydrogen as 100, it was equivalent to multiplying the corresponding value of Q (= 8) by 12.5. Consequently the several values of R, being calculated for equal weights of the mineral substances, are in each instance the weight of oxygen which is consumed by 12.5 parts of the reducing agent. Thus, 12.5 parts of carbon consume 33.33 parts of oxygen, etc.

The "duty" of any compound substance is the sum of the reducing powers of the elements of which it is composed. Thus, for the hydrocarbons:

Let a = the percentage of carbon,
b = " " " hydrogen,
c = " " " oxygen.

Then $R = (33.33\,a + 100\,b) - 12.5\,c$.

By a formula of this kind R can be calculated directly from the percentage-composition of any substance. Even in the complex metallic sulphides, arsenides, etc., R may be calculated from the composition by substituting in the formula the value of R for sulphur, arsenic, etc.

For carbon-monoxide the value of R may be calculated from the percentage-composition: carbon, 42.86; oxygen, 57.14.

$$\begin{array}{rr} 0.4286 \times 33.33 = & 14.28 \\ \text{Less } 0.5714 \times 12.5 \;\; = & 7.14 \\ \hline & 7.14 = R. \end{array}$$

Or from the equations and proportions:

$$CO + O = CO_2,$$
$$28 + 16 = 44.$$
$$28 : 16 :: 1 : Q = 0.5714,$$
$$8 : 0.5714 :: 100 : R = 7.14.$$

Marsh-Gas, CH_4.—Marsh-gas (methane) belongs to the paraffin series of volatile hydrocarbons; its composition is

Carbon, ...	75.00
Hydrogen, ...	25.00
	100.00

By oxidation, marsh-gas forms carbonic acid and water, thus:

$$CH_4 + O_4 = H_2CO_3 + H_2O.$$

$$16 : 64 :: \quad 1 : Q = \ 4.00.$$
$$8 : \ 4 :: 100 : R = 50.00.$$

Or, calculated from the composition,

$$33.33 \times 0.75 = 25.00.$$
$$100.00 \times 0.25 = 25.00.$$
$$\overline{50.00} = R.$$

Petroleum.—American petroleum is in great part a mixture of hydrocarbon oils of the paraffin series, represented by the formula C_nH_{2n+2}. The heavier oils average, approximately, carbon, 85 per cent.; hydrogen, 15 per cent.; corresponding very nearly to the formula, $C_{16}H_{34}$. Assuming that the carbon is completely oxidized to carbonic acid, and the excess of hydrogen to water:

$$C_{16}H_{34} + O_{49} = 16H_2CO_3 + H_2O,$$

from which $R = 43.36$.

Bitumen.—With bitumen is included mineral-tar, maltha, and the solid oxygenated hydrocarbons, such as grahamite. Their composition, while variable, usually falls within the limits of the analyses No. 1 and No. 2:

	No. 1.	No. 2.	No. 3.
Carbon, ...	80.00	89.00	81.00
Hydrogen, ...	14.00	11.00	10.00
Oxygen, ...	6.00	0.00	9.00
	100.00	100.00	100.00

The value of R for analysis No. 1 = 39.92, and for analysis No. 2 = 40.67. Analysis No. 3, of grahamite (gilsonite), with but 10 per cent. of hydrogen, gives a value for R of 35.88. In the above analyses it is probable that some nitrogen and sulphur are included with the oxygen, so that the deduction made for oxygen is slightly too great.

Bituminous Coal.—The average composition of bituminous coal may be stated as falling within the limits of the analyses 1 and 2:

	No. 1.	No. 2.
Carbon,	81.00	88.00
Hydrogen,	4.00	7.00
Oxygen,	15.00	5.00
	100.00	100.00

The duty calculated from the composition in the above analyses is, for coal No. 1, $R = 29.13$; and for coal No. 2, $R = 35.71$.

Lignite.—The composition of lignite is extremely variable and is much affected by the amount of decomposition it has undergone. Assuming that the analyses given below represent the ordinary limits of composition, the value of R for lignite No. 1 is 19.50, and for No. 2, 28.83.

	No. 1.	No. 2.
Carbon,	60.00	73.00
Hydrogen,	4.00	7.00
Oxygen,	36.00	20.00
	100.00	100.00

Native Humus Acid.—Dana gives the composition of humus acid from Bohemian brown-coal as $C_{46}H_{46}O_{25}$, which corresponds to:

Carbon,	55.31
Hydrogen,	4.61
Oxygen,	40.08
	100.00

$$998 : 1440 :: 1 : Q = 1.4428.$$
$$8 : 1.4428 :: 100 : R = 18.04.$$

Or, calculated from the composition,

$$\begin{aligned} 0.5531 \times 33.33 &= 18.44 \\ 0.0461 \times 100.00 &= 4.61 \\ &\overline{23.05} \\ \text{Less } 0.4008 \times 12.5 &= 5.01 \\ &\overline{18.04} = R. \end{aligned}$$

Sulphur.—Sulphur in ore-deposits may oxidize under certain conditions to sulphurous acid, but usually sulphuric acid is formed.

$$S + O_2 = SO_2;\text{ whence, } R = 12.50$$

$$S + O_3 = SO_3;\text{ whence, }\begin{cases} R = 18.75 \\ Q = 1.50 \\ S = 0.667. \end{cases}$$

Combined sulphur may, for convenience in calculating the duty of sulphides, be regarded as oxidizing to SO_4; as if all the oxygen combined with the sulphur and none with the base, giving the values $R = 25.00$; $Q = 2.00$; $S = 0.50$.

Sulphuretted Hydrogen.—The complete oxidation of sulphuretted hydrogen forms sulphuric acid, $H_2S + O_4 = H_2SO_4$, from which $R = 23.53$. When oxygen is deficient, water is formed, with separation of sulphur. The reaction then is:

$$H_2S + O = S + H_2O;\text{ whence, } R = 5.88.$$

Pyrite and Marcasite.—Three distinct reactions may occur in the oxidation of pyrite and marcasite (FeS_2):

(1) With liberation of sulphur, and formation of ferrous-sulphate—

$$FeS_2 + O_4 = S + FeSO_4;\text{ whence, } R = 6.67;\ Q = 0.533;\ S = 1.876.$$

(2) With formation of ferrous sulphate and free sulphuric acid, one atom of sulphur may be regarded as oxidizing to SO_3, the other to SO_4—

$$FeS_2 + O_7 + H_2O = FeSO_4 + H_2SO_4;\text{ whence, } R = 11.67;\ Q = 0.933;\ S = 1.072.$$

(3) When the oxidation of pyrite takes place with excess of air, ferrous sulphate is first formed, and by a complicated series of reactions, with further absorption of oxygen, the final result is the formation of limonite and sulphuric acid. The equation may be written:

$$4FeS_2 + O_{30} + 11H_2O = 2Fe_2O_3{,}3H_2O - 8H_2SO_4,$$
$$\text{Giving } R = 12.50;\ Q = 1.00;\ S = 1.00.$$

In the substitution of blende and galena for pyrite in secondary deposition, the reactions corresponding to equation (1) may be expressed:

$$FeS_2 + ZnSO_4 = ZnS + FeSO_4 + S.$$
$$FeS_2 + PbSO_4 = PbS + FeSO_4 + S.$$

Pyrite also deoxidizes sulphuric acid, with the formation of sulphuretted hydrogen and sulphur:

$$FeS_2 + H_2SO_4 = H_2S + S + FeSO_4.$$

The reduction of zinc- and lead-sulphate and lead-carbonate by pyrite is shown by the following equations, corresponding to equation (2):

$$FeS_2 + ZnSO_4 + H_2O + O_3 = ZnS + FeSO_4 + H_2SO_4.$$
$$FeS_2 + PbSO_4 + H_2O + O_3 = PbS + FeSO_4 + H_2SO_4.$$
$$FeS_2 + PbCO_3 + H_2O + O_3 = PbS + FeSO_4 + H_2CO_3.$$

In the presence of an excess of air, reactions, corresponding to equation (3), take place in the reduction of these soluble salts of zinc and lead, as follows:

$$4FeS_2 + ZnSO_4 + 11H_2O + O_{26} = ZnS + 2Fe_2O_3,3H_2O + 8H_2SO_4.$$
$$4FeS_2 + PbSO_4 + 11H_2O + O_{26} = PbS + 2Fe_2O_3,3H_2O + 8H_2SO_4.$$
$$4FeS_2 + PbCO_3 + 11H_2O + O_{26} = PbS + 2Fe_2O_3,3H_2O + H_2CO_3 + 7H_2SO_4.$$

Arsenic and Antimony.—The values of R for arsenic and antimony are obtained from the following equations:

$$2As + O_5 = As_2O_5;\ \text{whence, } R = 6.67.$$
$$2Sb + O_3 = Sb_2O_3;\ \text{whence, } R = 2.50.$$

Arsenopyrite.—The composition of arsenopyrite, FeAsS, is as follows:

Iron,	34.30
Arsenic,	46.00
Sulphur,	19.70
	100.00

The value of R may be calculated either from the reaction, the arsenic oxidizing to As_2O_5, or from the composition, as follows:

$$2FeAsS + O_{13} = As_2O_5 + 2FeSO_4.$$

$$\begin{aligned} 326 : \quad 208 :: 1 \quad &: Q = 0.638. \\ 8 : \quad 0.638 :: 100 : &R = 7.98. \end{aligned}$$

$$\begin{array}{rl} 0.197 \times 25 &= 4.92 \\ 0.46 \times 6.67 &= \underline{3.06} \\ & \ 7.98 = R. \end{array}$$

Enargite.—For enargite, Cu_3AsS_4, or $3Cu_2S, As_2S_5$, the composition and the computations are as follows:

Copper,	48.3
Arsenic,	19.1
Sulphur,	32.6
	100.0

$$3Cu_2S, As_2S_5 + 2H_2O + O_{35} = As_2O_5 + 6CuSO_4 + 2H_2SO_4.$$

One-fourth of the sulphur, or 8.15 per cent., is oxidized to SO_3, and the remainder (24.45 per cent.) to SO_4.

$$\begin{aligned} 786.4 : \quad 560 :: 1 \quad &: Q = 0.7121. \\ 8 \quad : 0.7121 :: 100 : &R = 8.90. \end{aligned}$$

$$\begin{array}{rl} 0.0815 \times 18.75 &= 1.53 \\ 0.2445 \times 25.00 &= 6.11 \\ 0.191 \times 6.67 &= \underline{1.27} \\ & \ 8.91 = R. \end{array}$$

Stibnite.—For stibnite, Sb_2S_3, the composition and the computations are as follows:

Antimony,	71.4
Sulphur,	28.6
	100.0

Dana gives the product of the oxidation of stibnite as valentinite, Sb_2O_3.

$$Sb_2S_3 + O_{12} + 3H_2O = Sb_2O_3 + 3H_2SO_4.$$

$$\begin{aligned} 336 : \quad 192 :: 1 \quad &: Q = 0.5714. \\ 8 : \quad 0.5714 :: 100 : &R = 7.15. \end{aligned}$$

Or, calculated from the composition,

$$\begin{array}{rl} 0.286 \times 18.75 &= 5.36 \\ 0.714 \times 2.50 &= \underline{1.78} \\ & \ 7.14 = R. \end{array}$$

Pyrrhotite.—Similarly for pyrrhotite, $Fe_{11}S_{12}$:

$$Fe_{11}S_{12} + O_{47} + H_2O = 11FeSO_4 + H_2SO_4,$$
$$\text{Giving } R = 9.40;\ Q = 0.752.$$

Ferrous Sulphate.—The reactions in the case of ferrous sulphate, $FeSO_4$, are as follows:

In the oxidation of pyrite and marcasite, a mixture of ferrous sulphate and free sulphuric acid is first formed. Weed* gives the products of the further absorption of oxygen as

$$H_2SO_4, Fe(OH)_3 \text{ and } Fe_2(SO_4)_3.$$

The reaction that takes place may be written:

$$6FeSO_4 + 2H_2SO_4 + 4H_2O + O_3 = 2(H_2SO_4, Fe(OH)_3) + 2(Fe_2(SO_4)_3) + H_2O.$$

Six parts of ferrous sulphate absorb 3 parts of oxygen; or, by reduction, 2 parts of ferrous sulphate absorb 1 part of oxygen.

$$304 : 16 :: 1 : Q = 0.05263.$$
$$8 : 0.05263 :: 100 : R = 0.66.$$
$$S = 19.1.$$

Summary.

The following table of comparative reducing powers gives the quantitative value, or gross amount, of the work done by each of the deoxidizing agents. It is necessary, however, to supplement these theoretic results by observations in the field, especially of ore-deposits undergoing decomposition and re-formation; and also by experimental research in the laboratory, in order to estimate accurately in each particular instance the chemical energy, or velocity with which the action takes place.

Fortunately, with respect to the greater number of the more important reducing substances commonly occurring in ore-deposits, the gravimetric power, or duty, and the chemical

* "The Enrichment of Gold- and Silver-Veins," by Walter H. Weed, *Genesis of Ore-Deposits*, p. 478; *Trans.*, xxx., 429, 430.

energy run nearly parallel; so that one may be taken as the measure of the other.

The results of these calculations confirm the observations made in the zinc- and lead-mines of the Joplin, Mo., region, in the investigation of the secondary formation of the ores, of the relative order of the reducing powers of the principal deoxidizing agents, viz.: 1, bitumen; 2, bituminous coal and carbonaceous shales; 3, marcasite and pyrite; 4, blende; 5, galena.

Ferrous sulphate appears to be exceptional; notwithstanding the extreme low duty (0.66), and notwithstanding that, in forming ferric sulphate, 19.1 parts of the salt combine with only one part of oxygen, yet in the zone of oxidation, where the chemical activities have full play in the breaking-up of an ore-body, it fulfils a special mission, at once oxidizing and reducing. Its chemical energy is such that it reduces cuprous oxide to the metallic state; a change which none of the other deoxidizing agents usually found in ore-bodies are able to accomplish.* Further, its field of operation is the zone of oxidation and that border-land where the zone of oxidation merges into the zone of reduction.

This low quantitative-value is in many instances more than offset by the large amount of ferrous and ferric sulphates continuously supplied by the progressive oxidation of the pyrite in the ore-deposits. The mine-waters lixiviating the decomposing ore, although the volume of the flow may be considerable, are frequently strongly acid from the free sulphuric acid and iron sulphates held in solution.

In conclusion, the hydrocarbons, combining the highest quantitative deoxidizing power with an intense chemical activity, are the most powerful of all reducing agents. The action of the solid oxygenated hydrocarbons, bitumen, bituminous coal, and the lignitic matter finely disseminated in shales, is greatly accelerated by the facility with which these carbon-compounds, when in powder, are carried by the circulating waters into every part of the ore-bodies.

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* "Enrichment of Gold- and Silver-Veins," by Walter H. Weed, *Trans.*, xxx., 431; *Genesis of Ore-Deposits*, p. 480.

TABLE.

THE RELATIVE REDUCING POWER, *R*, OR DUTY, OF EQUAL WEIGHTS OF THE ORGANIC AND INORGANIC MINERAL SUBSTANCES USUALLY OCCURRING IN THE ORE-BODIES, OR IN THE WALL-ROCK, OR INTRODUCED WITH THE CIRCULATING WATERS; HYDROGEN BEING ASSUMED AS 100.

	R.
Hydrogen (occurs combined with carbon), oxidized to H_2O,	100.00
Marsh-gas, CH_4 (carbon 75 per cent., hydrogen 25 per cent.), oxidized to $H_2CO_3+H_2O$,	50.00
Petroleum, C_nH_{2n+2} (carbon 85 per cent., hydrogen 15 per cent.),	43.36
Bitumen (carbon 89 per cent., hydrogen 11 per cent., oxygen 0 per cent.),	40.67
Bitumen (carbon 80 per cent., hydrogen 14 per cent., oxygen 6 per cent.),	39.92
Bitumen (grahamite) (carbon 81 per cent., hydrogen 10 per cent., oxygen 9 per cent.),	35.88
Bituminous Coal (carbon 88 per cent., hydrogen 7 per cent., oxygen 5 per cent.),	35.71
Bituminous Coal (carbon 81 per cent., hydrogen 4 per cent., oxygen 15 per cent.),	29.13
Carbon (graphite, etc.), oxidized to CO_2,	33.33
Carbon, oxidized to CO,	16.67
Lignite (carbon 73 per cent., hydrogen 7 per cent., oxygen 20 per cent.),	28.83
Lignite (carbon 60 per cent., hydrogen 4 per cent., oxygen 36 per cent.),	19.50
Native Humus Acid, $C_{46}H_{46}O_{25}$ (carbon 55 per cent., hydrogen 5 per cent., oxygen 40 per cent.),	18.04
Sulphur (combined), oxidized to SO_4,	25.00
Sulphur, oxidized to SO_3,	18.75
Sulphur, oxidized to SO_2,	12.50
Sulphuretted Hydrogen, H_2S, oxidized to H_2SO_4,	23.53
Sulphuretted Hydrogen, H_2S, oxidized to H_2O+S,	5.88
Pyrite and Marcasite, FeS_2 (oxidation of Fe to $2Fe_2O_3,3H_2O$; and S to SO_3)	12.50

Pyrite and Marcasite, oxidation to $FeSO_4$, . .	11.67
Pyrite and Marcasite, oxidation to $FeSO_4$ and S, .	6.67
Pyrrhotite, $Fe_{11}S_{12}$, oxidized to $FeSO_4$ and H_2SO_4,	9.40
Enargite, Cu_3AsS_4, oxidized to As_2O_5, $CuSO_4$ and H_2SO_4, ...	8.90
Chalcopyrite, $CuFeS_2$, oxidized to $CuSO_4$ and $FeSO_4$, ...	8.72
Covellite, CuS, oxidized to $CuSO_4$, . . .	8.39
Blende, ZnS, oxidized to $ZnSO_4$, ...	8.25
Arsenopyrite, FeAsS, oxidized to As_2O_5 and $FeSO_4$, ...	7.98
Calcium Disulphide, CaS_2, oxidized to $CaSO_4$ and S,	7.69
Stibnite, Sb_2S_3, oxidized to Sb_2O_3 and H_2SO_4, .	7.15
Carbon Monoxide, CO, oxidized to CO_2, . .	7.14
Bornite, Cu_3FeS_3, oxidized to Cu_2SO_4, $CuSO_4$ and $FeSO_4$, ...	7.01
Arsenic, oxidized to As_2O_5, ...	6.67
Tetrahedrite, $4Cu_2S.Sb_2S_3$, oxidized to Cu_2SO_4, $CuSO_4$ and Sb_2O_3, ...	6.39
Iron, oxidized to Fe_2O_3, ...	5.36
Iron, oxidized to Fe_3O_4, ...	4.76
Iron, oxidized to FeO, ...	3.58
Chalcocite, Cu_2S, oxidized to Cu_2SO_4, . . .	5.04
Galena, PbS, oxidized to $PbSO_4$, ...	3.35
Tellurium, oxidized to TeO_2, ...	3.20
Copper, oxidized to CuO, ...	3.15
Copper, oxidized to Cu_2O, ...	1.58
Antimony, oxidized to Sb_2O_3, ...	2.50
Rhodochrosite, $MnCO_3$, oxidized to MnO_2, . .	1.75
Siderite, $FeCO_3$, oxidized to Fe_2O_3, ...	0.86
Ferrous Sulphate, $FeSO_4$, oxidized to $Fe_2(SO_4)_3$, .	0.66
Magnetite, Fe_3O_4, oxidized to Fe_2O_3, . . .	0.46

The Camp Bird Mine,* Ouray, Colorado, and the Mining and Milling of the Ore.

BY CHESTER WELLS PURINGTON, THOMAS H. WOODS AND GODFREY D. DOVETON, OURAY, COLORADO.

(New York and Philadelphia Meeting, February and May, 1902.)

I.

The Camp Bird Mine, Mining and Ore-Transportation.

By Chester Wells Purington.

Situation.—The Camp Bird mine is in Imogene basin† (Fig. 1) at the head-waters of Cañon creek, a branch of the Gunnison, in the southern part of Ouray county, Colorado, towards the northern edge of the region known as the San Juan mountains, and about 10 miles W. of the continental divide. It is 8 miles by wagon-road from Ouray, the terminus of a branch of the Rio Grande Southern railway. The distance from Denver to Ouray is 387 miles by rail. In an air-line, the mine is 190 miles SW. of Denver. The altitude of the town, tunnel and buildings is 11,200 ft., and level No. 2 is 11,500 ft., and No. 1 is 11,670 ft., above sea-level. The lowest point of the lode-outcrop, which crosses the basin E. and W., has an elevation of 11,850 ft., and that of the highest point, on the divide between Imogene and Tomboy basins, is 13,250 ft. On the eastern slope of the Imogene basin (towards Ironton) the vein is less clearly defined on the surface.

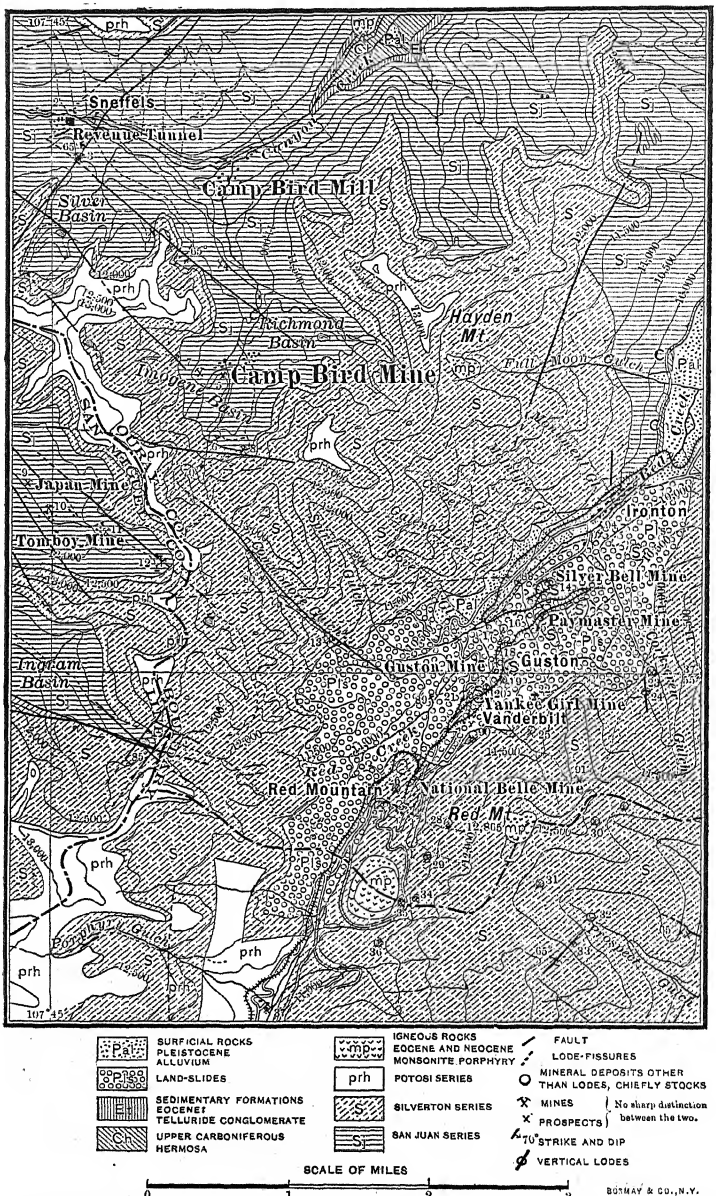
Ownership and Extent.—At the time of the writing of this paper, the property is owned by Mr. Thomas F. Walsh, and operated under the management of Mr. J. W. Benson.‡ It

* Since the receipt of this MS. by the Secretary, but prior to publication, the mine has been sold to an English company, and is known as the Camp Bird, Limited.

† The map of the north-west portion of the Silverton Quadrangle accompanying this paper is a reproduction of a portion of that accompanying Bulletin 182 of the United States Geological Survey, 1901, "A Report on the Economic Geology of the Silverton Quadrangle, Colorado," by Frederick Leslie Ransome. This work will be frequently referred to in the following description. The map is here reproduced by permission of the Director of the Geological Survey.

‡ I wish to acknowledge many courtesies extended by the manager and his staff, enabling me to collect the data for this paper.

Fig. 1.



Map Showing Situation of the Camp Bird Mine. Reproduced from Bulletin 182, United States Geological Survey. By Frederick Leslie Ransome. Geology by Whitman Cross.

For names of mines indicated by numbers on this map, see foot-note on opposite page.

comprises 129 patented mining-claims, covering more than 1000 acres, and a mill-site, 2 miles from the mine, in the cañon towards Ouray.

History and Present Improvements.—The Camp Bird claim was located in 1896 by Mr. Walsh, who in the same year bought the adjoining claims from H. W. Reed and others. The first work was done in the upper part of the present workings. A few men were kept working during the winter; and the following season the old 10-stamp "U. S." mill, a mile down the cañon, was utilized for milling the ore. The product steadily increased, and successive improvements were made as fast as development warranted. In 1898, buildings were erected at the present No. 2 level, and a 20-stamp mill, the nucleus of the present 60-stamp mill, was built on the Camp Bird mill-site. The present extensive surface-plant, consisting of the compressor-house, electrical station, aërial tram and large boarding-house, was erected in 1899 at the tunnel-, or No. 3-level, where a cross-cut tunnel (to be described under the head of Underground Development) was driven 2200 ft., to cut the vein 800 ft. below the surface.

Climate.—The San Juan region has a dry and healthy climate, the temperature ranging from 75° F. in summer to —25° F. in the coldest winter weather. Much snow generally falls in winter, but the rainfall is not excessive at any season.

Topography.—Toward the northern edge of the San Juan mountains a *mesa* country obtains, having a general elevation of 7000 ft., a part of the great basin draining into the Gulf of California. An abrupt rise of this plateau to heights of over 13,000 ft. is characteristic of the country about Ouray and to the south. The mountain country is, properly speaking, a par-

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Names of mines indicated by numbers on Camp Bird map, Fig. 1:

2. Revenue Tunnel. 3. Wheel of Fortune. 4. U. S. Depository. 5. Camp Bird, Main Adit. 6. Camp Bird, Upper Workings. 7. Hidden Treasure. 8. Hancock. 9. Japan. 10. Tomboy, Main Adit. 11. Tomboy, Upper Tunnel. 12. North Chicago. 13. Barstow. 14. Silver Bell. 15. Paymaster. 16. American Girl. 17. White Cloud. 18. Guston. 19. Scotch Girl. 20. Robinson. 21. Yankee Girl. 22. Grand Prize. 23. Midnight. 24. Carbonate King. 25. Alexandra. 26. National Belle. 27. Lake (Red Mountain). 28. Charter Oak. 29. Hudson. 30. Webster. 31. Galena Queen. 32. Mineral King. 33. Henrietta. 34. Carbon Lake. 35. Congress. 36. St. Paul. 37. Silver Ledge. 55. Poughkeepsie. 65. Mammoth. 88. Meldrum Tunnel. 89. Hammond Tunnel. 90. Genesee-Vanderbilt. 91. Summit. 94. Little Candies.

tially eroded plateau, the numerous streams cutting down their valleys with a cañon-like topography, forming precipitous slopes, and descending in torrents and cascades.

The heads of streams are found in comparatively flat basins or *cirques* of glacial origin, the ice-action responsible for their formation being entirely local, extremely recent, and, in places, still in progress. The timber-line is at about 11,500 ft., and the *cirques* lying above this altitude are treeless.

The sharp descents (Figs. 2 and 7) of the mountains from 13,500 to 7000 ft. are of great advantage in mining operations. Exposures, for the most part perfectly bare, of the sedimentary and volcanic rocks, offer special facilities for prospecting and exploitation.

The valley of Cañon creek, heading in Imogene basin, is thoroughly typical of the San Juan topography. From its source at 12,900 ft. down to an elevation of 9000 ft., 1 mile below the Camp Bird mill-site, the stream has an average fall of more than 800 ft. to the mile. The amount of depth gained by the No. 3 level of the Camp Bird, *i.e.*, approximately 1 ft. of depth for every 4 ft. of tunnel driven, may be taken as a fair average of the stoping facilities of the San Juan in general. It has rarely been necessary to resort to sinking in the mining operations of the region.

A remarkable feature, to which I have already referred,* is the presence, in the mountain-combs forming the divides, of jagged gaps, formed in large part by the weathering of the veins which cross them at various angles. Metalliferous zones so indicated do not, however, always prove to be of economic importance.

Geology of the District.—I quote from the paper already referred to,† in order to give a general idea of the rocks and their relations:

"The San Juan mountains rise on the northern edge of the great plateau region which has such widespread development in southwestern United States. This plateau is composed throughout of nearly flat sedimentary beds, extending in geological age from those lying directly on the Archean to the latest Tertiary. This vast formation has been in places tilted up, deformed, injected, and broken through by igneous rocks, the relics of whose activity have aided in making up the

* "Preliminary Report on the Mining Industries of the Telluride Quadrangle," *U. S. G. S.*, *18th Annual Report*, Part III., p. 751.

† *Op. cit.*, p. 758.

immense areas of rock which erosion, far-reaching and long-continued, has now exposed to view. In the San Juan region particularly, flows of volcanic lava are strongly developed, while dikes and sheets of rock of dioritic type have been intruded into and are intercalated with the sedimentary beds, and deep-seated *massifs* or laccoliths of diorite have deformed and rent the clastic beds with which they are associated. The San Juan mountains owe their origin and present elevation to the igneous agencies referred to above."

In the mountains surrounding Imogene basin (Fig. 3), and in the cliffs bordering the cañon below, the relations which the sediments bear to the overlying volcanics are illustrated typically and graphically on a stupendous scale.

Since the horizon of the sedimentary beds is at least 2000 ft. vertically below the present workings of the Camp Bird mine, this paper has little concern with them. Mr. Whitman Cross has most thoroughly studied the geology of the San Juan, and the reader is referred to his many able publications in the reports of the United States Geological Survey and elsewhere for detailed information along this line.*

The Ouray limestones exposed in the vicinity of Ouray are of Devonian age, and have an exposed thickness of 200 ft. in Cañon creek.

Overlying the Ouray limestone, forming cliffs with nearly vertical escarpments above the town of Ouray, lies the Hermosa formation of the Upper Carboniferous, which consists of alternating limestones, grits and sandstones, with a prevailing reddish color. The Dolores red-beds, conglomerates, sandy and shaly layers of the Triassic formation, overlie the Hermosa beds. The representatives of these two formations are not easy to distinguish without special examination, but, according to Messrs. Cross and Ransome, the Hermosa series has the greater development in Cañon creek. The total thickness of the two is not far from 2000 ft. These sediments, dipping gently to the west, are overlain directly by the unconformable Telluride conglomerate, which dips east. This conglomerate, easily recognized by the large and well-rounded included pebbles, attains on the walls of Cañon creek a thickness of only 100 ft. The pebbles are of many kinds—granite, schist, quartzite, red sandstone and eruptive rocks. Occasionally

* Especially to be consulted is the sketch of the geology of the Silverton Quadrangle, furnished by Mr. Whitman Cross, to accompany Mr. Ransome's monograph, *Bull. U. S. G. S.*, 182, p. 30, *et seq.*

they are over a foot in diameter. The formation becomes gradually thicker toward the west, attaining to nearly 1000 ft. in the Mt. Wilson district of the Telluride quadrangle.* The rocks with which this paper has mostly to deal are the complex series of volcanic flows, tuffs and breccias which overlie conformably the San Miguel formations.

The San Juan Breccias.—The first of them, in Imogene basin and the gorge of Cañon creek below it, is the San Juan series of andesitic breccias. This formation, dipping slightly to the east, and having a thickness of something over 2000 ft., appears in its lowest manifestation in the valley of Cañon creek at an elevation of about 9600 ft. The contact between it and the overlying intermediate series of andesites lies at an elevation in Imogene basin of approximately 11,750 ft. The series is recognized by its prevailing mottled appearance, with dull-red and green colors. It contains fragments, generally angular, of different andesites in a tufaceous matrix. Its origin is attributed by Mr. Cross partly to igneous agencies, while portions of its layers show a water-laid arrangement which implies the presence of lake- or stream-conditions during its formation. This heavy series of breccias and ash-beds is the most extensively developed in the San Juan mountains, and at its horizon most of the present productive mines of the district are situated.

The Silverton Series.—This formation, which was formerly known as the Intermediate,† overlies the San Juan breccias. It is a comprehensive group of andesitic and rhyolitic flows and tuffs. It has a thickness in Imogene basin of about 1000 ft., rapidly thinning toward the west and thickening toward the east. Mr. Cross says that its lowest member in most places is a rhyolitic flow or flow-breccia of peculiar character. Its largest masses, however, are said to be lavas of rhyolitic base containing many inclusions of both rhyolite and andesite.‡ Andesitic flows with prevailing dark color are very characteristic of the Silverton series. The upper contact between this series and the overlying Potosi series of rhyolites is often

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* *Geologic Atlas of the United States*, Telluride Folio, Cross and Purington, *U. S. G. S.*, 1899.

† *Telluride Folio, U. S. G. S.*, 1899.

‡ *Bulletin* 182, *U. S. G. S.*, p. 32.

marked topographically by well-defined benches in the upper parts of the basins.

The Potosi Rhyolites.—Above these benches the rhyolite ridges and peaks of the mountains, in the country about Imogene and the surrounding basins, make precipitous escarpments. The rhyolite cliffs of Imogene basin are ornamented by imposing rows of columns from 50 to 150 ft. in height, due to the structure of the glassy rhyolite, brought out by the intense weathering of these high altitudes. The effect of the various horizons of sedimentary and volcanic rocks on the fissuring and the ore-bearing veins of the district will be discussed later.

A large mass of monzonite-porphyry forms a prominent outcrop on the north side of the wagon-road to Ouray, 2 miles below the Camp Bird mills.

The Camp Bird mine-workings exhibit, in both the upper and the lower levels, toward the west end, occurrences in the form of dikes which resemble rather the Silverton type of andesite than the breccias. The horizon of the andesite-flows has apparently not been reached in the upper level of the mine, as the upper cross-cut is evidently in the breccias. These occurrences, therefore, seem to be somewhat abnormal.

In the adit-level, No. 3, at a point in the west drift 100 ft. west of No. 10 chute, blackish andesite, comparatively free from fragments, appears, at intervals, in the hanging-wall for the entire 1000 ft. of this drift. Such contacts as are traceable between this and the normal breccia appear to have an approximately NE. direction.

In the No. 2 level, 300 ft. above, in the west drift, at a point 1750 ft. from the junction of the cross-cut with the vein, an inclusion of rhyolite, the diameter of which did not exceed the height of the drift, was found in the hanging-wall; and for 300 ft. west of this point the dark andesite, characterized by conchoidal fracture, was continued, and was then suddenly cut off, the normal pink and green breccia taking its place. For 1000 ft. farther along the drift, dikes of the andesite appear at intervals in the walls.

In the extreme west end of the No. 1 level, above, the same rock, of dark color, but containing numerous fragments, has recently been found. In all other parts of No. 1 drift, and in the stopes above, the rock resembles the San Juan breccia.

Judging from these occurrences, it is likely that there is, at the general level of the Camp Bird workings, a somewhat complicated mingling of the San Juan formation with this purer andesite. Perhaps it is allowable to suggest that here and farther to the west there exists a stock of the intermediate andesite, one of the sources of this upper series of lavas. The rhyolitic flow, mentioned above as the characteristic lower member of the Silverton series, was not identified in the mine-workings.

The Veins and Fissuring.—My views concerning the origin and nature of the fissure-systems in this portion of the San Juan country have been set forth at some length in a paper on the Telluride district.* I have seen no reason to change the opinion that most of the ore-deposits of this region have been formed in pre-existing open fissures. A recent study of the mining district north of Silverton and east of Telluride lends strong confirmation to this opinion. The neighboring deposits of Red Mountain, as Mr. Ransome has pointed out, exhibit what is very likely "a local modification of the general fissuring of the region."†

The Telluride quadrangle shows four prevalent directions of fissuring, along which the productive ore-bodies have been developed. These systems are found to be approximately (1) E.–W., (2) NE.–SW., (3) N.–S., and (4) NW.–SE. The E.–W. system of fissures is the one exemplified in the Camp Bird ore-deposit. The vein has an average direction not far from N. 80° W., and, like the majority of the prominent veins of this immediate section, dips south. The dip varies within small limits in different portions of the workings, averaging 70° from the horizontal. The Camp Bird vein follows, in the main, two sets of fissures, one striking N. 87° W., and one striking N. 72° W. Subordinate to these is a set striking N. 51° W. The dip of all these systems is to the south. By reference to the Telluride bulletin it will be seen that the N. 87° W. set of fissures is prominent throughout the district to the east of Imogene basin, extending even as far as Mt. Wilson. It is the direction taken by the Pandora vein,‡ prominent in the

* *Op. cit.*, pp. 764, *et. seq.* † *Bull.* 182, *U. S. G. S.*, p. 108.

‡ Mr. Ransome concludes that the Camp Bird and the Pandora are probably the same lode.

workings of the Smuggler-Union mine, and it is also the direction of several prominent veins in Bear creek to the southeast of Telluride. A strong fissure-zone bearing this direction was also noted in the Virginius basin. The N. 51° W. direction which the Camp Bird vein occasionally assumes corresponds to one of the prominent directions of the Tomboy vein, which is not far away.*

I think that the fissures of the San Juan mountains are separated by alternating narrow and wide intervals; that, in a given system, these alternations occur in more or less rhythmical sequence; that wide belts of crushed material have resulted from the intersections at narrow angles of the narrowly separated zones, representing separate systems of fissures; and, finally, that the position of the larger ore-deposits of the district was determined by the situation of such intersections,—it being adopted as a necessary hypothesis that the present veins represent filled fissure-zones. The Camp Bird vein has evidently been formed by the intersection of three closely spaced zones on the three sets of fissures above specified, its direction being mainly determined by the first two. To this fact it owes its remarkable width. Illustrations of the feature mentioned in connection with the Tomboy vein, namely, that of the ore following its previous direction for a distance in one direction after its switching to another, are frequent and well-marked. At chute No. 10, level 3, on the vein turning to N. 87° W. from N. 72° W., a number of small stringers continue in the first direction. In the east end of No. 3 level a set of joints, carrying more or less ore, strike N. 51° W., and continue into the hanging-wall after the vein takes a N. 72° W. direction.

Occasionally it is difficult to tell in which direction to drift at the intersection of two sets of fissures, as at No. 6 chute in the east drift, 3d level, where a false lead was followed for 200 ft., N. 87° W., after the main lead had switched to N. 72° W. Even in close proximity to the andesitic mass which is referred to below, where there was a tightening and practical obliteration of the fissures for over 500 ft., the western continuation of the lead affords illustration of the constancy of the fissuring tendencies along definite lines.

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* Telluride Report, *U. S. G. S.*, p. 778.

The Camp Bird is an illustration of the larger type of vein. Its average width, from 6 to 7 ft., is somewhat greater than that of the San Juan veins in general, which are characterized rather by permanency in longitudinal and vertical dimensions. Smooth walls are not a feature of the Camp Bird deposit, a well-defined flat surface on either foot- or hanging-wall being the exception. Slickensides, striations, groovings or carunculated surfaces have not been observed. The presence of finely-comminuted and re-cemented fragments of the vein-matter, referred to below, may indicate that relative motion of one wall on the other has at some former period taken place; but there is no evidence of recent motion of such a character.

With perhaps one or two insignificant exceptions, there is no indication of faulting subsequent to the formation of the ore. Near No. 11 chute, in the west end of the lower level, a normal fault was seen; the south side of a small stringer having moved down about 3 inches. Other such cases have been observed; but the throw was always small. On the No. 2 level, 1750 ft. west of the cross-cut, there is a local pinch of the vein, which does not appear either in the lower or the upper level, and which there is no evidence to connect with any faulting of the vein. On No. 2 level the pinch was nearly coincident with the body of dark andesite already described. This rock was harder than the normal country-rock, and broke with a conchoidal fracture. As the vein retained its normal width both above and below, it may be suggested that the andesitic magma here crystallized into a hard and dense bleb, rendering any widening of the first fissure difficult. After passing through the area of andesite and mingled andesite breccias described above, a distance of nearly 900 ft., the vein resumed its normal width.

It has not been found that the width of the veins of this region suffers, as a general rule, any consistent change as they pass from the San Juan series into the intermediate andesites, or *vice versâ*. Both these formations gave way to the fissuring forces with practically the same facility. In the Potosi rhyolites, however (the rocks now appearing on the tops of the mountains), the veins are generally small, and sometimes difficult to trace. The rhyolite is often referred to as "cap-rock," and the veins are said to be "cut off" on entering it; but this expression is misleading, since, in every case that has come

under observation, the fissuring is continued, though with much smaller manifested results, through the rhyolite to the tops of the mountains.*

The Vein-Filling.—The Camp Bird vein does not offer a great variety, either of gangue-minerals or metallic sulphides. Of the values, which consist of gold, silver and lead, 96 per cent. are gold. This occurs both free in quartz and combined mechanically with other metallic minerals. Unmistakable evidence of the presence of tellurium has been found in tests on the richer portions of the ore. The lead occurs as galena, which contains also all the silver, outside of that which is necessarily associated with the gold. Silver sulphides and sulpharsenites, generally present in the upper portions of neighboring San Juan veins, are, so far as known, entirely lacking here.

The principal gangue-mineral is white, opaque, generally crystalline quartz. White, massive quartz is found on the edges of the main vein, interlaminated with country-rock, and often sprinkled with crystals of pyrite and galena, and flakes of chalcopyrite. Within the vein, the quartz which is richest in gold has a dull luster, and consists of closely-packed crystals, often showing spherical aggregates, in which the pyramidal terminations of the ore at the center of the sphere and the striations characteristic of the prism-faces of this mineral are very strongly marked upon the radiating crystals, as if there had been breaks in the continuity of crystallization from aqueous solutions. A typical example of rich Camp Bird ore is described by Mr. Ransome (p. 89, *Bull.* 182), and is reproduced in an accompanying drawing in a remarkably beautiful and graphic manner. The centers of these spheres, which are commonly 3 in. in diameter, are frequently occupied by more or less impure rhodonite.

Open cavities are also very frequent, varying from almost microscopic size to a diameter of 10 ft. A remarkable one, found in a stope at the west end of No. 3 level, was 10 ft. across, 12 ft. high, and lined with quartz crystals, together with a crystalline mass of calcite, and possibly some siderite, the

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* Mr. Ransome has arrived at conclusions somewhat different from mine regarding the nature of the fissuring in the area under consideration. *Bull.* 182, *U. S. G. S.*, p. 208.

whole being coated with oxides of iron and manganese. Quartz crystals 5 in. in length are sometimes found in these cavities.

Calcite occurs throughout the ore, though never in large quantity. In vugs in the stope near the east end of No. 3 level were found beautiful masses of pink crystals of "dog-tooth" spar.

Rhodonite, remarkable for its color and its curious association with the quartz and metallic minerals, occurs abundantly—never in large masses, but generally in lamellæ from 1 in. down to microscopic width. Fig. 4 represents a typical occurrence of the rhodonite, quartz and calcite, with their relations to the metallic minerals. Fluorite is mentioned by Mr. Ransome.

Chlorite, usually associated with good values, is present to a small extent.

Of the metallic sulphides, the principal is normal pyrite, either finely crystalline or massive, and either associated with quartz and rhodonite, or impregnating the bands of country-rock included in the vein or constituting the walls. It cannot in general be said to play an important part as a matrix for the gold, since, as is shown by Messrs. Woods and Doveton in the succeeding portions of this paper, an interesting feature is the increase in the amount of pyritic impregnation which the wall-rock undergoes in passing from west to east. Whether it carries a corresponding increase in gold-values has not been fully determined.

Zinc-blende is very rarely seen in the ore; but the presence of zinc is proved by the analyses given in the following part of this paper.*

Magnetite, a somewhat unusual constituent of gold- and silver-veins, has been shown by laboratory tests to be present in considerable quantity in the Camp Bird, although it cannot be recognized by the inspection of hand-specimens of the ore. It occurs intimately mixed with galena in the white quartz which is commonly free from other metallic minerals except gold. The mixture of galena and magnetite produces in the quartz wavy lines, or indistinct cloudy bands, which are an almost in-

* Mr. Ransome mentions its occurrence in connection with the dark bands accompanying the rich ore.

fallible indication of accompanying high gold-values. The exceeding fineness of the particles of these minerals makes it impossible to distinguish either the galena or the magnetite by their physical characters. Fig. 4 illustrates a common occurrence of this mixture in bands in connection with the parallel bands of rhodonite and the accompanying finely crystalline quartz. This structure is not unlike the California vein-material ordinarily referred to as "ribbon-rock."

Of the ore-minerals, properly so-called, galena, containing silver as well as lead, is the most conspicuous. As already noted, it is associated with magnetite in a peculiar manner. Most of it, however, occurs in bands from 1 to 4 in. wide, and crystallized with a fair degree of coarseness in solid masses, which generally follow with regularity, for considerable distances, one or the other of the walls. Galena also occurs, sprinkled in the white quartz with streaks of rhodonite.

Chalcopyrite occurs, according to its habit in the veins of the San Juan, in irregular spots and blotches through the vein. If there be any special peculiarity in its occurrence here, it is that it appears to be associated rather with the included portions of the country-rock than with the quartz. As will be seen in the chapter on milling operations, which follows, the amount of chalcopyrite must be small, since the percentage of copper in the ore is insignificant.

Arsenic has been recognized in traces by Mr. W. F. Harris in the assay-office, but no compounds of this metal have ever been seen in the ore.*

Gold and Silver.—As already observed, the gold of the Camp Bird vein is associated with mixtures of galena and magnetite, and to a less extent with pyrite. Pure white quartz, with no visible metallic minerals, is found to contain good values in gold. The gold occurs finely divided, and is rarely seen in the ore. Its fineness is .740, the chief impurity being silver.

The silver occurs with galena, and as an alloy with the gold. It is possible that silver sulphides and sulph-arsenites occur in the ore, but hitherto they have not been found.

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* I am indebted to Mr. G. W. Pickard, of Boston, for much assistance in the mineralogical and chemical determinations.

Secondary Minerals.—Under this term are included the products of decomposition, induced, for the most part, by the percolation of surface-waters. They are few, and offer no features of special interest. Limonite, due to the decomposition of pyrite, is found in the more weathered parts of the vein, and lead and iron carbonates are also present in small quantity. Wad and the other oxides of manganese are found to a limited extent, mostly as coatings on the ore. A substance resembling kaolinite, perfectly white and pure, with a soapy feel, was found near the center of the vein, in the stope over No. 8 chute, in the Blue Bird level.

The deposit here described is of the normal filled-fissure type. Countless examples may be seen, in the mine-workings, of perfectly angular fragments of country-rock included in the vein-matter. Yet certain features which it possesses have caused the writer to question whether "spaces of dissolution"* do not exist. The large cavity or chamber once referred to (shown in Fig. 5) appears, from the section shown (a drawing from a face exposed by recent shots in the stope), to have been cut out of a previously-formed portion of the vein. The walls of the cavity were as rounded as those formed in limestone by percolating waters, and the bottom was occupied by 2 ft. of bluish and white clayey material, arranged in layers, and containing fragments of quartz-combs and separate crystals.

It is assumed that the original deposition of the ores in mechanically formed fissures was through the agency of heated waters. It is not pertinent to the discussion of the case in point whether these waters were of meteoric or of deep-seated origin. Granting that they entered the open fissures penetrating the plutonic, volcanic and sedimentary rocks of the region at a conceivably moderate depth,† still they were charged with the minerals in solution necessary for the formation of the ore and gangue minerals of the future veins. The waters, containing alkaline carbonates, were solvents for all the metals, earths and SiO_2 encountered in their passage through the rock-mass, but not, to any extent, at the earth's surface; this took place

* Posepny's term.

† Lindgren, "Gold-Quartz Veins of Nevada City and Grass Valley," *17th Ann. Rept. U. S. Geol. Survey*, 1895–96, Part II., page 176.

under extraordinary conditions of heat and pressure which, it is generally conceded, must exist at the deep-lying vein-forming horizon. The solution finally entered the fissures in part as sulphides, and partly as alkaline carbonates partially charged with sulphides.

Moreover, such circulating waters were in large, rather than small quantities. Conceive a portion of an open fissure, situated at the deep region,* into which water (which has traversed, by capillary action, the interstices of a rock-mass of unknown lateral and vertical dimensions) finds entrance. This water will, as Posepny† states, mount in the open channel, cooling and depositing its mineral load during the ascent.

It is admissible that the whole of the fissure may not be filled by the material precipitated from the water passing through it at a certain period; that at periods, separated from one another by no great time intervals, pulses of heated water may find access to and ascend in the fissure successively; and that pauses may occur in the circulation, allowing, temporarily, the still conditions which Mr. Ransome‡ suggests. It is also conceivable that varying conditions may obtain in different portions of the rock-mass which contributes its mineral load to the waters. Thus at one period the water may enter the fissure with more power to dissolve; at another period, with more ability to precipitate or leave its load, which is already in solution.

It is therefore proposed, in explanation of the occurrence illustrated by Fig. 4, that the space or vug may have been dissolved out of the normally formed vein at a period shortly after the original deposition of the ore; and that the agent responsible for this solutive action was water, whose solvent powers for SiO_2 and metallic sulphides were not wholly exhausted at the period of its migration from the capillary interstices of the rock-mass to the comparatively open space offered by the fissure.

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* That the passage of water through rocks is of a capillary nature is interestingly illustrated by the researches of sanitary engineers. For example, Mr. John C. Thresh (*Water and Water-Supplies*, Phila., 1901, p. 351) says, that even in fissured strata, water collected from deep wells is remarkably free from bacteria, these having been removed from the water in its passage downward, by the rock acting as a capillary filter.

† Posepny, *The Genesis of Ore-Deposits*, 1892, p. 24; 2d ed., 1901, p. 27.

‡ *Bulletin* 182, *U. S. G. S.*, p. 136.

Such water, in ascending, would first part with the silica and some of the silicates. The deposit of clay-like material found in the bottom of this cavity, in stratified arrangement, may have resulted either soon after the cavity was formed or at a period considerably later. It is likely that this material consists largely of kaolinite and sericite. Quartz crystals, small and well formed, are found in it.

There is considerable evidence in different portions of the deposit of a re-arrangement and re-cementing, by secondary silica and by calcite, of the original constituents of the vein. It is not easy to see, however, what agencies could have been at work to produce by dissolution, in material commonly regarded as insoluble, under conditions which obtain at or near the earth's surface, cavities of such size as the one cited. If the occurrence has any bearing on the question of secondary changes and arrangement in ore-deposits, it seems to indicate that such changes as occurred in this particular deposit took place far below the earth's surface. In other words, that this re-arrangement of the ore is not a surface-phenomenon, but a concomitant or approximately immediate result of the conditions controlling the original deposition of the ore.

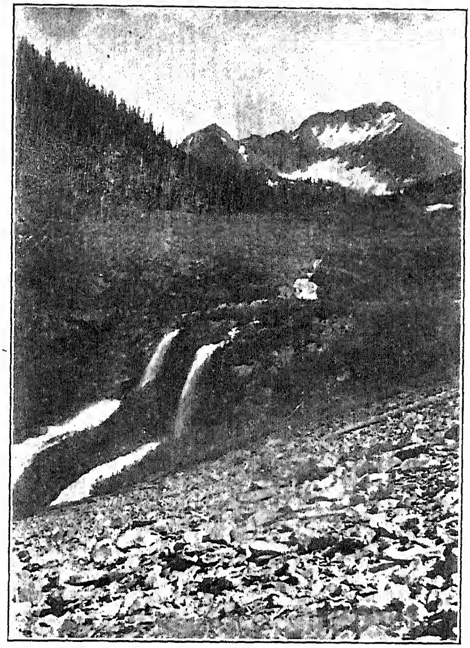
Origin of the Ore.—I am not at present prepared to enter into this subject with regard to the Camp Bird vein. I have found nothing in the course of my examination to justify a conclusion as to the source of the ore different from that already expressed in the Telluride Bulletin.* Certain features of this deposit, notably the different character of its ore and values from many of the veins in the neighboring portion of the Telluride quadrangle, render it possible that a full investigation of the surrounding conditions would throw further light on the age of this deposit, with reference to those about it. Unfortunately, such an investigation was not possible before the preparation of this paper.

A somewhat remarkable occurrence may be mentioned at this point, which was brought to the writer's attention by Mr. Laurence Cronin, the mine-superintendent. It was a jagged and angular inclusion in the vein (in the stope over No. 4 chute, in No. 3 level), about 12 in. long and 6 in. broad, and consist-

* *Op. cit.*, p. 824.

ing of a mixture of very finely crystalline and amorphous silica, of laminated structure and slightly pinkish tinge. Closely examined, it was seen to contain very small druses lined with quartz crystals. Hydrochloric acid causes effervescence in all parts of the specimens taken. Two other similar but smaller inclusions were observed in the center of the vein (here 6 ft. wide), near the one described. In the largest mass,

Fig. 2.

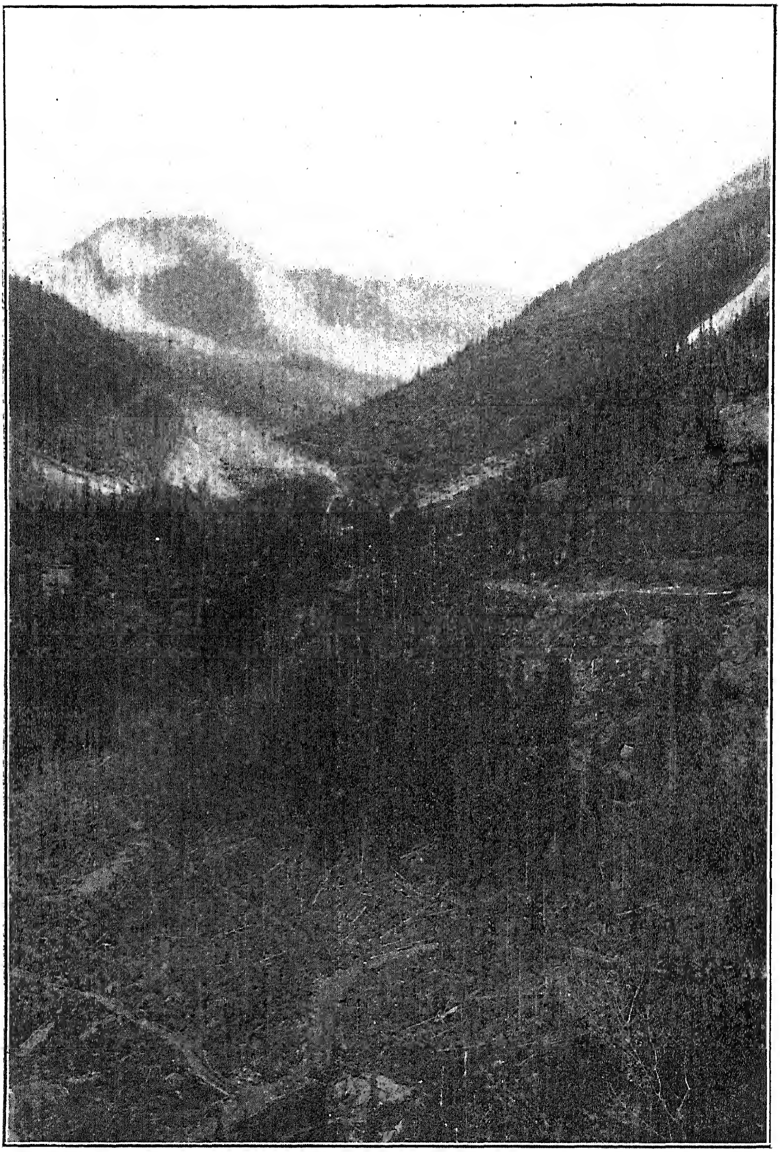


Looking up Cañon Creek from below Imogene Basin.

the laminations were nearly at right angles to the dip of the vein.

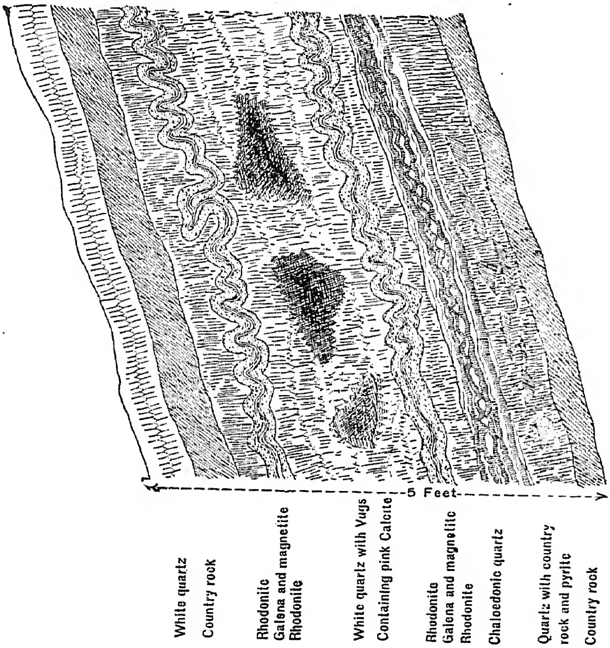
These inclusions had, in fact, all the appearance of fragments of silicified sedimentary rock; and their position at this horizon seems almost inexplicable. An analogous occurrence was, however, found, several months ago, by Mr. Arthur Collins, manager of the Smuggler-Union property, in the upper workings of that mine, and consequently at a horizon fully as high as in this case. That was even more remarkable; since the

FIG. 3.



Imogene Basin, looking south.

FIG. 4.



Portion of vein in East drift, Level No. 3, showing Mineral association.

FIG. 5.

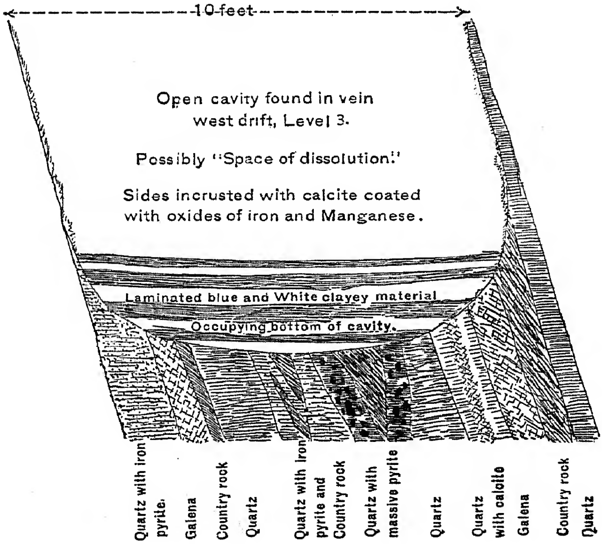
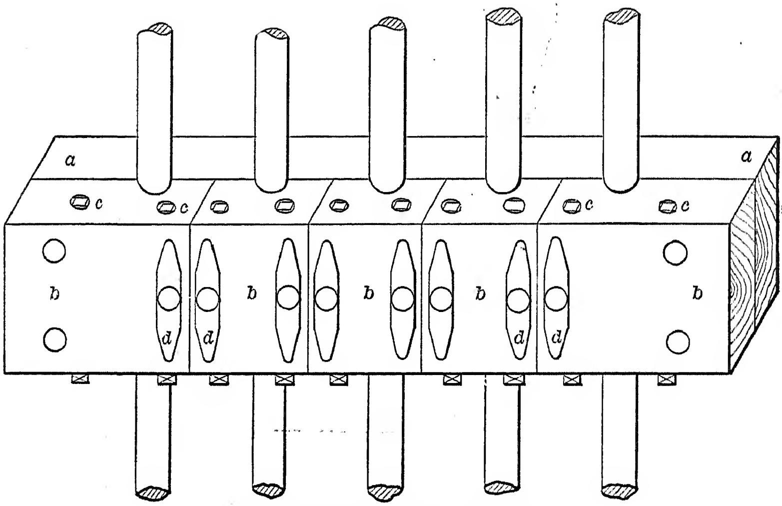
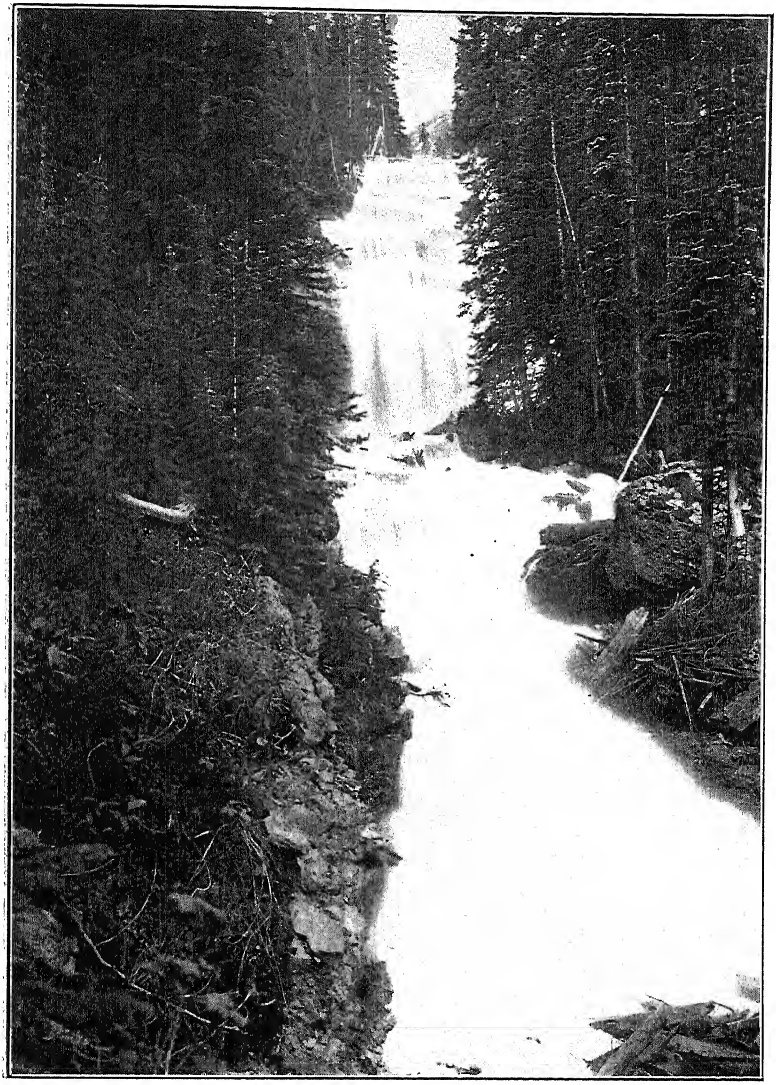


FIG. 6.



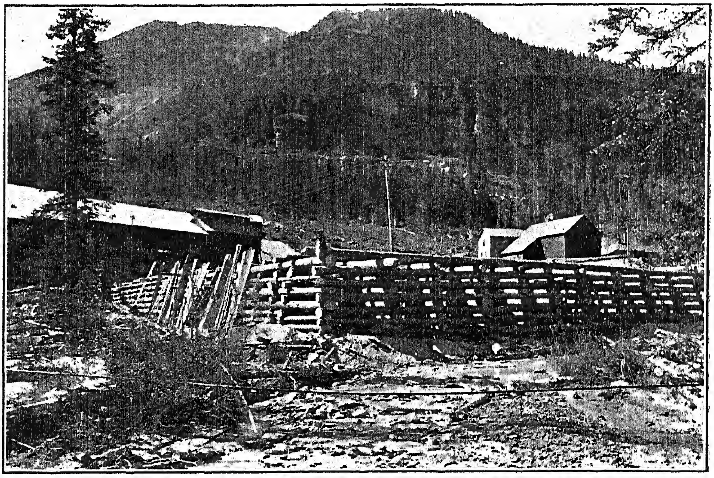
The MacDonough Stamp-Guide.

FIG. 7.



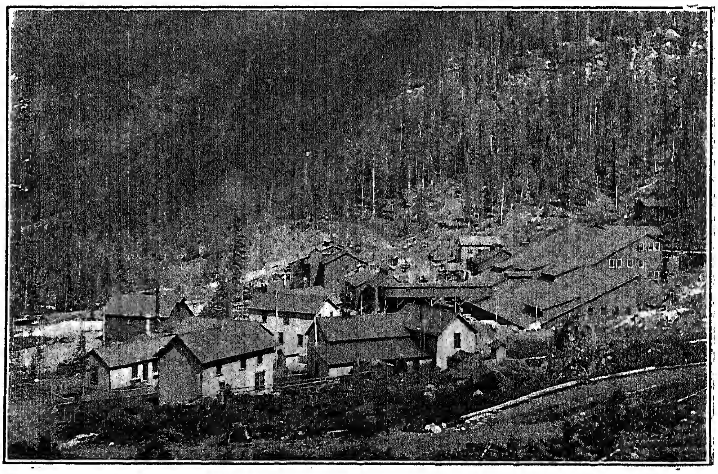
Mill Water-Power; summer conditions.

Fig. 8.



Dam Built to Form Reservoir for Collecting Slimes.

Fig. 9.

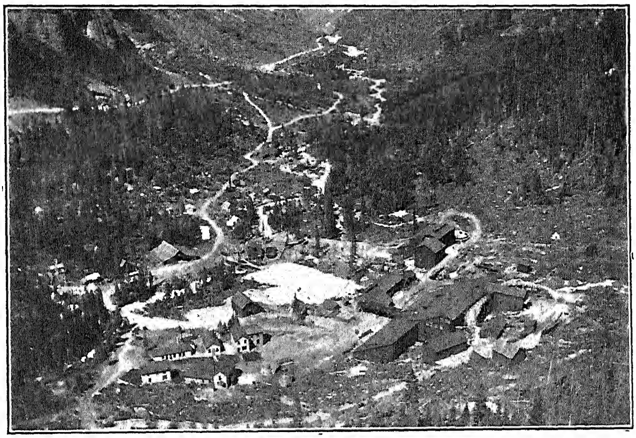


Camp Bird Mills.

inclusions, though smaller, were, to all appearance, metamorphosed limestone, containing what appeared to be fossil crinoid stems. Mr. Collins kindly allowed me to examine the specimens shortly after their discovery.

The writer is unwilling to adopt, without further evidence, the opinion that these fragments have been brought up from below. Yet from what nearer source they could have been derived it is impossible to see. It is hoped that this point will be discussed by members who have observed similar phenomena.

FIG. 10.



Camp Bird Mills. Looking down Cañon.

The Vein in Depth.—Judging from experience in working neighboring veins, it appears likely that the Camp Bird will continue in depth with undiminished width to approximately 2000 ft. below the present level of the lowest workings. Nor is there reason to expect that its values will decrease within this distance. The San Juan ore-deposits are exceedingly young, geologically; and, to put it briefly, it is the tops, and not the stumps, of veins which are now exposed to view. The mine under consideration lies in the upper portion of the heavy San Juan formation, which is known to have a thickness of at least 2000 ft. in this district. General experience here has shown no impoverishment of the veins which carry the bulk of their values in gold, in passing from the upper to the lower

portions of this formation. In the case of many of the silver-bearing veins, the rich sulphides and sulpharsenites of silver found at the upper levels have not continued in depth. On the other hand, cases have occurred where values have increased with depth.

The influence of the country-rock on the width of veins in this district is well known. In the underlying sediments, deposits as valuable as those found in the breccias are not likely. In the San Miguel conglomerate, veins operated in the Telluride and Silverton districts have been proved fairly valuable. The thickness of this rock, however, where it underlies Imogene basin, must be less than 100 ft.; and therefore its influence on the vein has no great importance.

In the Carboniferous and underlying sediments in the vicinity of Ouray, deposits of the precious metals have been worked at a profit for several years. It may not, therefore, be assumed that the values in the Camp Bird vein will not continue through the Triassic beds. Should the mine be worked to the depth of the underlying limestones, there is a possibility that heavy bedded sulphide-deposits will be encountered along the line of the vein.

Occurrence of the Ore in the Vein.—As in most typical fissure-veins, shoots of ore occur in the Camp Bird deposit. Hitherto, however, these shoots have not been found to have a definite pitch in the plane of the vein; at least, very little correspondence appears to exist in the directions taken by their boundaries. Shoots have been worked continuously in the mine from the surface to the depth of 800 ft., which is that of the lowest present workings; and there is no indication that they do not continue farther down. Since they vary in horizontal length, it seems fair to assume that the greatest dimension is measured on the dip of the vein.

This portion of the San Juan region is not characterized by a definite arrangement of the ore in the veins. In some individual cases a succession of shoots has been found; but there is no agreement in this regard between one vein and another. For example, Mr. Arthur Winslow* mentions the fact that in the Liberty Bell mine, near Telluride, the results of sampling

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* *Trans.*, xxix., 296.

proved that the vein, so far as developed, was practically one shoot of low-grade ore 2000 ft. in length. This occurrence is not to be correlated with the neighboring veins in Marshall basin, nor do those veins among themselves present any uniform arrangement of ore.

The development of the Camp Bird vein has not afforded, thus far, evidence of local secondary enrichment or impoverishment. The secondary enrichment of veins, recently the subject of no little discussion, has been lately studied in the San Juan region by Mr. Ransome, who concludes that the phenomenon has there a limited manifestation. If, as I understand from the paper by Mr. Walter Harvey Weed on "The Enrichment of Gold and Silver Veins,"* such enrichment below the "iron hat" depends on the presence of a large amount of pyrite in the ore, it would scarcely be expected that the phenomenon would play a great part in the veins of the San Juan in general. If it has any manifestation in the district, observations thus far seem to indicate that those veins carrying silver values in excess of gold have been the ones subject to it. In the Camp Bird vein, the uniformity of values hitherto encountered in going from higher to lower levels seems to preclude the belief that there has been a transfer of values from one horizon of the deposit to another.

Development.—The main cross-cut, 2200 ft. long, at level No. 3, runs south to cut the vein. The two upper levels, also, are opened by cross-cuts. The total length of development-work, including cross-cuts, drifts on the vein, stopes, raises, mill-holes, shafts and winzes, is between 5 and 5½ miles. In the west end of the workings, over 1500 ft. of depth beneath the top of of the mountain has been gained.

The main cross-cut at No. 3 level is 7 by 7 ft. in the clear, and timbered for the first 420 ft. from the entrance (that is, so long as the tunnel is in the "slide-rock") with square sets (posts and caps 12 in. square). After entering the solid rock, no timbering is required. The upper cross-cuts, also, are timbered only in the slide-rock. In general, it may be said that, throughout the mine-workings, timbering is required only in the chutes or mill-holes, raises, winzes, and the floors of stopes.

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* *Trans.*, xxx., 424.

The ground in the mine stands remarkably well, several stopes from 10 to 20 ft. wide having required no timbering.

The main cross-cut is lighted with incandescent lights 100 ft. apart. In the No. 2 and No. 3 levels and cross-cuts, the 30-lb. steel-rail track is 22 in. wide. Compressed air is conducted into the main cross-cut by a 6-in. pipe, the size of which is successively cut down as the air passes through the different workings to various parts of the mine. A 2- by 1-ft. ditch for water is cut in the lower cross-cut; and there are smaller ditches in the levels.

From the upper level, and stopes above, the ore is handled entirely by gravity, through chutes, to the lower level, then trammed by mules to the ore-bins at the mouth of the main adit, and dropped into the tram-buckets, which run by gravity over the aërial tram-line, 9000 ft. long, to the mill. From all other parts of the mine the ore is similarly handled. No ore is trammed out to the surface at the No. 2 or No. 3 levels. From the lower level, 9 end-dumping cars, of a little over 1 ton capacity each, are run in a train. The installation of electric tramming is now under consideration. The average quantity of ore trammed out is a little over 200 tons per day. Shafts are now being sunk on the vein from the lower level, and one of these is already 200 ft. deep. Part of the tonnage making up the daily mill-run is taken from this shaft.

In chutes and raises, stulling with 5-ft. centers is used. Mill-holes are put in at intervals of 50 ft.; and, as often as necessary for getting the ore from the upper levels, these are continued upward as raises. Every alternate chute is supplemented with a man-way and slide for steel.

In stoping, it has been the custom to stull and lag over the top of the drift, forming a floor for the power-drills. Recently there has been put in practice, where ground is sufficiently solid to warrant it, a system introduced by Mr. Cronin, the mine-superintendent. When a new stope is to be started, a raise is put up from 6 to 10 ft., according to the solidity of the ground, and timbered as usual. From the top, the vein is run on as if a drift were being started. The machine-men thus stand on a solid block of ore in place, instead of stulls and lagging. The pillar thus formed is lengthened as far as it is desired to carry the stope, say 50 ft., to the place of the next

chute, and the broken ore falls on the solid pillar, the timbering being thus practically replaced. The pillar is, of course, always accessible as ore, when its extraction is desired.

The mine is at present well off for timber, the lower level being situated below timber-line, and there being a fairly heavy growth of spruce on the side of the mountain near by. Spruce timber is plenty along the mountain sides from the mine-workings to the mill.

It is the practice in all the mining operations to take out only about 40 per cent. of the ore broken in stoping, allowing the rest to remain in the mine. It is found that this 60 per cent. of broken ore very nearly fills the space occupied by the total original ore in place. An advantage of this system is that there is no necessity for going into the walls for waste to fill the stopes, since these are continually filled with broken ore. For the most part, levels, raises, chutes and winzes have been run in ore; and at present the percentage of waste trammed out is very small.

Cross-cuts and main levels are carried 7 ft. above the track, with a grade of 4 in. to 100 ft.

All drifting and breaking is done by machine-drills, operated by compressed air* from the compressor-plant at the mouth of the main cross-cut. This consists of two 75-H.P. cross-compound compressors, with air-cylinders of 19- and 12-in. diam. respectively, and 16-in. stroke; and one 200-H.P. compressor (2-stage type), driven by a cross-compound Corliss engine. This has air-cylinders of 22-in. and 13-in. diam., and 36-in. stroke. At present, 19 machine-drills are used in the mine, the size most in favor having $3\frac{1}{4}$-in. cylinder. More of these will soon be installed. Hercules powder of 40 per cent. strength is used. Holes are fired just before 4 o'clock, leaving 3 hours for the mine to clear of smoke. The two 8-hour shifts go on at 7 o'clock, night and morning. Natural ventilation, supplemented by that supplied by the air from the drills, affords exceedingly good air in nearly all parts of the workings.

Electrical power for the compressors is furnished by the Telluride Power Transmission Co., from the line which comes over the mountains from the Ophir Loop station (a distance

* The writer is indebted to Mr. William Scheele, the master mechanic, for data concerning the compressed-air plant.

along the line of 21 miles), which carries 10,000 volts of 3-phase alternating current, and "steps down" at the mine transformer-house to a voltage of 400. The upper floor of the compressor-house carries the three Westinghouse 3-phase induction-motors: two of 100-H.P. each, and one of 200-H.P., which are connected severally by pulleys with the three compressors.

A supplementary steam-plant is provided in the compressor-house, by which the compressors can be run, if necessary.

Labor.—About 200 men are now employed in and about the mine, the day-shift comprising 130, and the night-shift 70. There are very few outside men. Wages are as follows, per day:

Large-machine men,	$4.50
Large-machine helpers,	4.00
Small-machine men,	4.00
Blacksmiths,	4.00
Blacksmiths' helpers,	3.25
Timbermen,	4.00–4.50
Timbermen's helpers,	3.00
Shovellers,	3.00
Tramway men,	3.50
Trammers,	3.00
Engineers,	4.50

A large boarding-house at the mouth of the lower cross-cut, lighted by electricity, heated by steam, provided with baths, and supplied in all parts with running-water, under 80 lbs. pressure, provides comfortable lodgings for $1 a day. Much attention is given to maintaining proper sanitary conditions.

Tram.—The Bleichert aërial wire-rope gravity-tram, which transports the ore from the tram-bins to the mill, has been in operation without breakage of any sort for over three years. The entire length is slightly over 9000 ft.,—the vertical distance between the two terminal stations being 1350 ft. The tram-line is in two sections, the angle-station being at about two-fifths the distance from the upper station to the mill. Tension-boxes are provided at both the angle-station and the mill-station. This line was constructed, including all towers, in the short space of 48 days. More than 200,000 tons of ore have already been transported on it. All supplies for the mine are transported over the tram, the weight of the loaded ore-buckets supplying the power.

Water.—The quantity of water encountered in the Camp Bird mine-workings is variable. In winter, as might be expected in a region where frost penetrates the ground to such an extent, the amount of water is much smaller than in summer. The three levels are drained separately; and in January, 1902, less than 100 gals. a minute was issuing from the lower cross-cut, while a proportionately smaller amount came from the No. 2 and No. 1 levels. In summer, on the other hand, it is said that as much as 2500 gals. per minute sometimes flows out.

As an example of the winter-conditions, the shaft now being sunk from the lower level on the vein makes only 1500 gals. of water in 24 hours, or but little over 1 gal. per minute.

A few words concerning the level at which ground-water is encountered may be appropriate. Where the ground remains frozen to a considerable depth during six months of the year, as may be said to be the case here, the decomposing influences of the atmosphere are much retarded. Outcrops of veins, therefore, frequently present perfectly fresh metallic sulphides. Consequently, the presence of unoxidized sulphides cannot be, as in a flat country, a criterion for determining the level of the ground-water. This level, if it may be so-called in this rugged region, doubtless has the form of a plane more or less conformable with the configuration of the overlying topography, and lying at a considerable distance beneath the surface. It is not possible to believe that anything but surface-waters have been encountered as yet in the workings of the Camp Bird; and in the surrounding district, where a similarly variable quantity of water is encountered, it is extremely likely that all is surface-water. That there is a considerable amount of ground-water in this region, however, can hardly be doubted, in view of the evidence furnished by the mine-workings at lower altitudes. Mr. H. C. Lay* has recently made some valuable observations in regard to this point.

So far as the writer has observed in this portion of Colorado, the greater the depth to which mines have been worked, the more water has been encountered. Since, in some cases, from 2500 to 3000 ft. of depth below the surface has been reached

* "Recent Geological Phenomena in the Telluride Quadrangle," etc., *Trans.*, xxxi., 558.

without getting below the level of the present valleys, it is reasonable to suppose that, when further sinking is undertaken, water will be encountered in even greater amount. The observed facts here are hardly in accordance with those noted in connection with the examples of deep mines, cited by Prof. J. F. Kemp,* in which little water is encountered.

Postscript.

(January 25, 1903.)

The writers are indebted to The Camp Bird, Limited, through the courtesy of Mr. John Hays Hammond, Consulting Engineer for the Company, for the following data concerning the history and product of the Camp Bird mine from October 31, 1896, to January 1, 1903. Mr. A. Chester Beatty, who kindly transmitted the data at Mr. Hammond's request, states that the records for the month of December, 1902, were not available, and, in consequence, an estimate was necessary in order to bring the total production up to January 1, 1903:

Total tons milled and smelted, ...	195,461
Total gross value recovered, ...	$6,530,430.00
Gross value recovered, per ton, ...	33.41
Profits, ...	4,315,798.00
Expended on construction and purchase of properties,	696,000.00

The Camp Bird was transferred from Thomas F. Walsh to its present owners, The Camp Bird, Limited (an English company), May 12, 1902.

II.

The Camp Bird Mill.

By Thomas H. Woods and Godfrey D. Doveton.

The output of the Camp Bird mine may be considered ideal milling-ore, yielding its values readily to amalgamation, vanner-concentration, and subsequent cyanide treatment of the tailings. The method of treatment, while it offers few new features, is of interest as an example of the reduction of a docile ore. The following is a synopsis of the method employed: (1) Breaking

* "The Rôle of the Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., p. 169, and *Genesis of Ore-Deposits*, p. 681.

with Blake crushers, (2) pulverizing with stamps, (3) copper-plate amalgamation, (4) vanner-concentration, and (5) the direct treatment of the tailings by cyanide.

The Breaking of the Ore.—The loaded tram-buckets, after leaving the tramway-terminals, are trammed on suspended tracks to the crusher-house and dumped on sets of grizzlies. Each ore-bin, of which there are three, is equipped with a grizzly at each end, the fines passing directly through the bars to the main bins, while the coarse falls to the crusher-jaws, and thence to the ore-bins. The grizzlies, 12 ft. long, set at an angle of 45°, pass all material under 2 in. The rock-breakers, Blake pattern, 9 by 15 in., set at 2 in., are placed directly under the center of the ore-bin. This arrangement insures a comparatively good mixture of the fine and the coarse rock.

Ore-Bins.—Each of the bins has a capacity of one hundred and eighty tons. The floors are set at an angle of 45° and lined with $\frac{1}{4}$-in. boiler-iron. The chutes, from the bins to the automatic feeders, are controlled by a rack-and-pinion gate. In addition to these ore-bins there is a large reserve storage containing sufficient ore to run the mill for six days.

The Stamp-Battery—Foundations.—Trenches, 10 ft. in depth, are blasted out of the solid rock, and the mudsills placed in the bottom are securely wedged against the sides of the pit, and then packed with concrete. Upon these the mortar-blocks, of 2-in. plank set on end, are spiked and bolted together. Two sets of binders, front and back, are bolted to the mortar-block, but not to the battery-timbers. The writers are of opinion that less jar is transmitted to the battery-timbers when they are not bolted to the mortar-blocks, because then they do not get the jar due to the impact of the stamps.

The mortar rests upon a rubber-gasket, $\frac{1}{4}$ in. thick, and is bolted to the mortar-block with 4 anchor-bolts, front and back. The battery-frame timbers are made of the best grade of dressed Oregon fir. The king-posts are bolted to the street-sills with $1\frac{1}{8}$-in. bolts of Norway iron. All bolts in the framing are of Norway iron, since cast-iron is of little use when subjected to such vibration. The king-post is also bolted to the ore-bin above and below the cam-shaft floor. The mortars are of the Homestake pattern, but amalgamation is not conducted inside. It has been found advantageous here to use the battery as a pulverizing

machine only, for a very perfect amalgamation is secured on the apron-plates.

The cam-shafts are of hammered steel, 6 in. in diameter and 14 ft. long, fitted with Blanton cams. Both steel and cast-iron cams are used, but steel cams have given the most satisfaction.

Babbitted journal-boxes are still in use, although two cam-shafts are running in bearings without babbitt. In the writers' experience, however, babbitted boxes are to be recommended, for the following reasons:

(1) The alignment of the shaft can be more easily kept true with a babbitted bearing, because, no matter how carefully the battery foundations are erected, a small amount of settling is sure to take place. This increases the difficulty of shimming up a cam-shaft bearing or a battery-post.

(2) In replacing a broken shaft with a new one, more perfect bearings can be obtained. Bearings without babbitt have a tendency to wear to a greater or less extent.

During the last four years, with an average of 45 stamps per shaft, four cam-shafts have been broken. This remarkably clean record is due in great part to the excellency of the battery foundations. Extra cam-shafts are, however, always kept on hand ready for use.

The Stamps.—The stamps weigh 850 lbs. each, and drop 100 times per minute. The speed has recently been changed from 90, with the result that the capacity has been greatly increased, a better splash obtained, and a consequent reduction in slimes observed. The order of drop is 1, 4, 2, 5, 3. The drop is set at 6 in., and, as the shoes and dies wear, re-set at 8.

The even distribution of the weight in stamps is a matter frequently overlooked by machinery-manufacturers, too much weight being often apportioned to the stem and boss, with a tappet too light for the work it has to do.

The stems are made of soft steel, 14 ft. in length and $3\frac{1}{8}$ in. in diameter, and weigh 380 lbs. When broken at both ends they are sent to the machine-shop, thoroughly annealed, turned in a lathe, and again put into service. The tappets weigh 80 lbs., and are made of both cast-iron and steel. The latter is much preferred; the steel tappets rarely break, have a much longer life, and seldom require facing.

The automatic feeders are mostly of the Challenge type, but

four are of the suspended type. The latter are much preferred, as they take up but little space, and allow free movement around the mortars. The feed-tappets are attached to the middle stamp-stem. Solid feed-collars have been in use until recently, but are now replaced by a sectional feed-collar. By its adoption a great deal of time is saved in replacing a broken feed-stem, as no chipping of the broken stem is required. The bosses are of cast-iron, weigh 250 lbs., and are attached to the stem in the usual manner. The plugs are removed with careful charges of giant powder.

The shoes weigh 140 lbs. when new, and are attached to the bosses with hard-wood shims. Soft wood has been found useless for this purpose. Three kinds of shoes are in use in the mill at present, and a comparative table showing the cost, life and wear of iron per ton of ore crushed may be of interest:

	Chrome Steel.	Forged Steel.	Cast-Iron.
Cost per lb. at the mill, .	8 cents.	$6\frac{2}{3}$ cents.	$3\frac{1}{5}$ cents.
Weight when new, .	140 lbs.	137 lbs.	135 lbs.
Weight when discarded,	35 lbs.	40 lbs.	40 lbs.
Actual life, . . .	106 days.	72 days.	41 days.
Wear of iron per ton of ore crushed, . .	.318 lb.	.43 lb.	.75 lb.

The cost of iron per ton of ore milled was, with the chrome-steel shoes, 2.5 cents; with the forged-steel, 2.75 cents; and with the cast-iron, 2.4 cents.

As the result of the above experiments, and taking everything into consideration, the chrome shoe was ultimately decided upon as the most economical at the present time. Forged-steel, chrome-steel and cast-iron dies have been in use.

The chrome-steel dies were of the sectional type, which possess some advantages in being readily removed from, and replaced in, the mortar. They also give a more constant depth of discharge. On account of the short life of the die-top, however, and the annoyance caused by chips of steel from the mine getting between the top and the base, they were discarded for a solid forged-steel die. The relative wear of the different dies is shown in the following table:

	Chrome Steel	Forged Steel.	Cast-Iron.
Cost per lb. at the mill, .	8 cents.	$6\frac{2}{3}$ cents.	$3\frac{1}{5}$ cents.
Weight when new, .	76 lbs. (tops).	143 lbs.	140 lbs.
Weight when discarded,	22 lbs.	50 lbs.	50 lbs.
Actual life, . . .	41 days	80 days.	42 days.
Wear of iron per ton of ore crushed, . .	.42 lb.	.36 lb.	.75 lb.
Cost of iron per ton of ore crushed, . .	3.36 cents.	2.30 cents.	2.4 cents.

Chuck-blocks, 4 in., 3 in. and $1\frac{1}{2}$ in., are employed to keep the depth of discharge as constant as possible. The height of discharge is normally 5 in., and at this the sliming is reduced to a minimum and the maximum crushing capacity is attained. Forty-mesh slot-screens have been in use until recently, but have been replaced by 25-mesh No. 29 wire-cloth. The wire-screen is infinitely superior and cheaper, having a greater discharge area, and the constant annoyance experienced by chips when the slot-screen was in use is entirely abolished. The batteries can also be fed very much lower than formerly, with desirable results.

The cost of a slot-screen at the mill is $1.49, and that of a wire-cloth screen $0.85. The former has a life of three days, or $46\frac{1}{2}$ tons of ore, the latter a life of six days, which corresponds to the crushing of 93 tons of ore. Thus the slot-screen costs 3.2 cents per ton of ore crushed, while the wire-cloth screen costs but .9 of a cent.

The discharge-area of the screens is 50 in. by 8 in. The stamp-duty is at present 3.11 tons (dry ore) per stamp per day. Sectional guides are in use on 40 heads of stamps. This type of guide was designed by Mr. W. MacDonough, superintendent of construction. It is a quick guide in turning stems, and is very firm and rigid in construction. As may be seen in the drawing (Fig. 6), specially-cast washers (d, d) are used, instead of the ordinary round washers, for the purpose of more securely holding the guide over its full width. The one-half inch bolts (c, c) are put in crosswise, in order to prevent the splitting of the guides. On 20 of the stamps the Fargo guide is in use, but is not so satisfactory.

The water (20 gallons per minute) is supplied to the mortar through the feed-slot with $1\frac{1}{2}$-in. pipe. This method of feeding the water insures a thorough mixture with the ore. For some

unaccountable reason, fewer stems have been broken since the back-feeding has been adopted. When front-feed was in use here (the water being supplied through five small pipes), frequent annoyance was experienced through the tendency of the pipes to jar loose and leak. They were also much in the way when repair-work was in progress.

Amalgamating-Practice.—The plates are 16 ft. long, 53 in. wide, of raw annealed copper, $\frac{1}{8}$ in. thick, and have a fall of $1\frac{1}{2}$ in. per ft. They are delivered to the mill in 4-ft. sections. The method of preparing the plate for service is as follows: The surface is scoured thoroughly, by vigorous rubbing with tailings or a piece of brick, to remove all traces of oxide and expose the bright surface of the metal. Strips of blanket are placed on the table along the sides and across the line of junction, and the sections of copper securely screwed to the table with brass screws counter-sunk. Iron screws rust so rapidly that they are of little use for this purpose. The plate is now thoroughly washed with hot water, and again with a strong solution of lye. The quicksilver is applied a little at a time, and the plate thoroughly amalgamated by vigorous rubbing with a blanket-brush. A little dilute cyanide is used during this operation. A new plate, during the first few days it is in service, is dressed usually every two hours, and little or no amalgam is removed, except, perhaps, from the head, until a coating has accumulated.

Clean-up and Dressing.—The methods pursued in the daily clean-up of the mill are as follows: The battery being hung up, the plate is carefully washed, the amalgam at the head (sometimes hard and crystalline, due, in the writers' opinion, to the manganese present in the ore) is slightly softened by sprinkling with a small quantity of quicksilver and rubbing with scrubbing-brushes, after which the amalgam, commencing at the bottom and working upwards, is removed by means of rubber scrapers. Knives are seldom used, except possibly at the very head. After the amalgam is removed the plates are again sprinkled with mercury, which is thoroughly spread and worked into the copper. Following this operation the plates are brushed with very fine whitewash-brushes, and riffled crosswise. During this latter operation the mercury is slightly drawn to the sides of the plate, consequently the brushes are

drawn lengthwise along the sides, from the bottom to the top. This finished, the feed-water is turned on and the stamps again dropped. The time of cleaning up and dressing is about 20 minutes to each plate. The plates are cleaned the full length at the morning clean-up, while in the evening the top only is cleaned, unless the ore is unusually rich.

The plates are dressed every three hours, and no mercury is fed into the mortar. Weak solutions of lye and potassium cyanide are employed while dressing, and lime is occasionally supplied to the batteries to neutralize the acidity of the feed-water and the ore. No difficulty is experienced in keeping the plates free from verdigris by these methods. An average extraction of 75 per cent. is obtained at this stage of the milling, with a resulting loss of only .142 to .166 oz. quicksilver per ton.

The amalgam recovered in the mill is immediately conveyed to the amalgam-room, and there cleaned and retorted. The impurities which adhere to the plates are very tenacious, and on this account it is necessary to grind the crude amalgam in mortars, for the purpose of mechanically separating the sulphurets and sand. The clean-ups are submitted to two separate grindings. In the first, after softening with additional mercury and grinding for a time in hot water, the batch breaks, and the partially clean amalgam sinks to the bottom, while most of the impurities float on the top and are skimmed off. The amalgam remaining is then squeezed through canvas bags and freed from excess of mercury. It is then further cleaned by a second grinding, so that very few impurities remain. After being subjected to a further squeezing, the amalgam is retorted. The yield is about 40 per cent., and the fineness of the gold thus recovered is .740.

The sulphurets and other impurities in the ore have a tendency to foul the mercury, and it is therefore necessary to retort all of it before using it again in the mill. The gold is weighed and shipped daily to the mint.

The pulp from each ten stamps, after leaving the plates, is run to traps—simply wooden boxes, 12 by 15 by 8 in.—suspended on iron hangers, with a motion given them similar to that of a vanner. They make 180 strokes, of $\frac{3}{4}$-in. throw, per minute. On the discharge side they are fitted with long copper lips con-

nected with the vanner-launder. The pulp is delivered to the center of the trap, and this and the reciprocating motion of the box prevents the settling and packing of the sands and concentrates, allowing ample opportunity for the amalgam and mercury, which escapes from the plates, to deposit.

The traps have proved very efficient, and at no time has the presence of mercury been detected in the cyanide solutions. Once a week the traps are cleaned and 50 oz. of mercury distributed among the six.

The pulp, on leaving the plates and passing through the traps, is delivered to thirty-six concentrators. Sizing is carried on in pointed boxes, the pulp from each 20 stamps running to 6 machines; and, as double concentration is in vogue, it is elevated and treated again on a second row of vanners.

The final tailings are delivered to the cyanide-works.

Concentration.—The concentrator equipment consists of 30 six-foot Frue vanners, and six Wilfley tables. The first row of vanners is fitted with amalgam-savers in the form of copper plates fitted to the pulp-distributors. The vanners are set up and anchored to massive sills which run the entire length of the building.

Too much care cannot be given to the erection of the concentrators, if good results are to be obtained, the least lost motion in the machines being very noticeable in the results, both at the front and back end of the table. The machines on the coarse side run 190 revolutions per minute, and are given an inclination of 3½ in. in their entire length. On the slime side a speed of 182 revolutions is allowed, with an inclination of 2½ in. The speed and inclination are based upon careful experiments. Corrugated belts are in use on the head machines in the front row. They give very good satisfaction in handling the coarsest of the pulp and have a much greater capacity, although the tailings have a slightly higher value and the resulting concentrates are not quite so clean. However, in view of the second concentration, they are to be recommended.

The Wilfley tables have a speed of 240 revolutions per minute. They give good satisfaction, especially in regard to capacity, which is much greater than that of the Frue vanners.

All these vanners are equipped with sulphuret rollers, and the mud-boxes of each machine are connected with settling-tanks.

Little trouble is experienced from the belt elevators, which travel at a speed of 410 ft. per minute, lifting 15 ft. The pulleys are key-seated and set-screwed, and an 8-ply belt is used, having a life of 14 months.

Lines of track are run in front of each row of vanners, to facilitate handling the sulphurets, which are trammed direct to the dryer-building. The dryer proper consists of iron-lined shoots or bins, set at an angle of 45°. They are 4 ft. wide and are fitted at the bottom with iron gates, for withdrawing the dried concentrates. In the center of each bin are coils of pipe heated with exhaust steam from the mill-engine. The concentrates remain in the dryer from three to four days, and by that time the moisture is reduced to about 3 per cent.

Concentration is carried on at a ratio of about 15 to 1, and the average extraction in the concentrating department is about 10 per cent. of the whole, giving an average total saving, in the stamp-mill alone, of 85 per cent.

The average composition of the concentrates during an extended period has been:

	Per cent.
Silica,	18.00
Galena,	7.04
Copper pyrites,	8.20
Iron pyrites,	30.15
Magnetite,	7.00
Blende,	16.50
Rhodonite,	4.80
Calcite,	9.00
	100.69

The analysis of the ore from which these concentrates were produced is as follows:

	Per cent.
Silica and insolubles,	85.20
Galena,	.50
Copper pyrites,	.80
Iron pyrites,	6.50
Magnetite,	.50
Blende,	3.00
Rhodonite,	2.50
Alumina,	1.50
	100.50

The analyses of the concentrates and the ore were made for the writers by Mr. W. F. Harris.

The cost of milling the ore in summer is from 48 to 54 cents per ton; in winter, from 68 to 72 cents per ton.

Power.—The boiler equipment consists of a battery of three Babcock and Wilcox 150-H.P. water-tube boilers, supplying steam to a 250-H.P. tandem compound Corliss engine. To this the main stamp-mill line shaft is direct-connected. By means of a counter-shaft, a 100-H.P. Westinghouse generator is connected, which, in turn, furnishes power to the cyanide mill, machine shop and carpenter shop. The Telluride Power Transmission Co. has erected a station for reserve electrical power, from which power can be obtained in case of emergency.

In summer (Fig. 7) a 7-ft. Pelton water-wheel, working under 175 lbs. pressure, supplants the steam equipment. During the latter part of the winter, when the water-supply is decreased, owing to natural conditions, a dam (Fig. 8) is used for settling the water. The slimes accumulated by this dam are treated during the summer months by cyaniding.

The mills, shops, boarding-houses and offices are lighted by electricity. The exhaust steam from the engine, which has never over 1½ lbs. back pressure, is utilized for heating the mills by a system of radiators, as well as for running the dryer, the water of condensation being returned, by means of pumps, to the boilers.

A common store-house, both for the mine and mill, forms part of the plant equipment, all supplies being charged separately to the various operations.

Costs of Milling Per Ton of Ore.

Crushing or breaking,	Labor,	$0.065
	Repairs and maintenance,	0.006
Pulverizing,	Labor,	0.059
	Wear of iron,	0.048
	Screens,	0.009
	Repairs and maintenance,	0.065
	Lubricants and sundries,	0.002
Amalgamation,	Labor,	0.090
	Quicksilver,	0.007
	Chemicals and sundries,	0.001
Concentration,	Labor,	0.042
	Repairs,	0.030
Power, light and steam heat,	Labor,	0.042
	Fuel,	0.160
	Lubricants and sundries,	0.006
Superintendence, day and night,		0.075
Total cost of milling,		0.707

In these costs the separate treatment of the concentrates, per ton of ore milled, is not included.

Cyanide-Works and Treatment of Tailings.

General Description.—The cyanide-works (Figs. 9 and 10) are arranged for the direct treatment of the vanner-tailings. They have a capacity of about 200 tons per day, but at the present time they treat 150 tons daily. Owing to the position of the mill, the tailings have to be elevated a height of 40 ft., and this is accomplished by a No. 4 centrifugal sand-pump, running at 650 revolutions. The column-pipe is 4 in. in diameter, and 315 gals. of pulp are delivered to the settling-vats per minute. The linings of the pump are of manganese-steel, and undergo erosion quickly, so that the life of a lining averages about six, and under favorable circumstances eight to ten, weeks. A duplicate pump is kept in reserve, ready for immediate use. When worn out, the pump is removed to the machine shop, re-lined, and new collars, if necessary, are fitted on the shaft. The master mechanic, Mr. William Scheele, has arranged an excellent device for controlling the suction opening; it is a sliding valve, of boiler-plate, set in a frame, and attached to the suction-nipple by set-screws. The slide is attached to a lever, which, in turn, is connected to a float. As the water rises in the settling-box the valve is opened wider, and *vice versâ*. This arrangement makes it impossible for the pump to take air, and the pump works very smoothly. A Cornish float was formerly in use, but it was not a success.

The cost of elevating the pulp, which settles in the leaching-vats, amounts to a total of 3¾ cents per ton, of which 3¼ cents is for power and ½ cent for maintenance and repairs. A tailings-wheel for elevating the tailings is under consideration, and, though the first cost will be large, the writers are convinced that this will speedily be balanced by the reduction in cost of power, and the greater freedom from wear and tear.

The pulp is distributed in the vats by Butters and Mein distributors, which have been found satisfactory, the slimes passing off at three slime-gates (fitted with slats 4 in. deep, set in a groove), placed at equal distances round the circumference of the vat. No attempt is made to classify the pulp before delivery to the vats, owing to the impracticable nature of the

ground. The separation of the slimes takes place in the leaching-vats, from which they are conducted and settled in the slimes-dam (Fig. 8), and stored for subsequent treatment during the summer months. The leaching-vats in the older portion of the mill are arranged for double treatment, and there are four sets of 100-ton vats and one set of 200-ton vats.

The bottom of the upper vat is set 4 ft. 6 in. above the top of the lower. It rests on girders of channel-iron, which, in turn, are supported on steel columns in the center and round the circumference.

A series of experiments were conducted on 100-ton and 200-ton charges, to determine the adaptability of these tailings to single direct treatment, and the results were so flattering that, in a recent addition made to the mill, two vats, 40 ft. in diameter, with a 6-foot stave, arranged for single treatment, were installed.

In the future additions to the mill, vats of even greater diameter, probably 60 ft., will be installed, for single treatment.

Some comparative notes relative to single and double treatment are given on page 545.

Grading-Tests.—A grading test of the product settled in the vats may be of interest:

(1) Product settled in a 24-ft. vat, 100-ton charge.

(2) Product settled in a 30-ft. vat, 200-ton charge.

(3) Product settled in a 40-ft. vat, 300-ton charge.

Grading-Test (1).—Two of these vats are filled at once, each vat getting about half the pulp.

	Per cent.
Retained on 40-mesh,	12.60
" " 60- "	22.90
" " 80- "	12.60
" " 100- "	0.90
" " 120- "	19.10
" " 200- "	11.60
Passed 200- "	20.30

Grading-Test (2).—This vat is filled alone.

	Per cent.
Retained on 40-mesh,	17.60
" " 60- "	22.60
" " 80- "	14.80
" " 100- "	1.60
" " 120- "	16.80
" " 200- "	16.00
Passed 200- "	20.60

Grading-Test (3).—The two vats, used for single treatment, are filled singly.

			Per cent.
Retained	on	40-mesh,	11.80
"	"	60- "	22.60
"	"	80- "	12.80
"	"	100- "	1.00
"	"	120- "	19.20
"	"	200- "	10.00
Passed		200- "	22.60

The leaching-vats are fitted with a filter-bed consisting of pine slats 1¼ in. in width and 2 in. deep, placed 1¼ in. apart. In the wooden vats the slats are simply nailed to the bottom, and abut against an annular ring slightly rounded on the periphery, and placed one inch from the staves. The slats are also rounded on the top, and, to admit of free circulation of the solution, crozed on the bottom at regular intervals. Over the slats is tacked a layer of cocoa matting, 2 in. smaller in diameter than the floor of the vat. A 12-oz. duck filter-cloth, about 6 in. larger than the floor, is stretched over the matting, and firmly grouted down with an inch rope between the ring and the staves. In the upper series of vats a heavier duck is required, the friction of the shovels being sufficient to wear out the cloth in about 5 months. In the lower series, however, an 8-oz. duck will wear for 15 to 18 months. The matting will last a considerable time,—4 or 5 years.

A No. 4 centrifugal pump is used for returning the solution from the sumps to the storage-vats, or directly to the leaching-vats. Zinc shavings are used as a precipitant, and the precipitating plant consists of four extractor-boxes, containing the strong solution. Each of these boxes is divided into six compartments, 36 in. long, 24 in. wide and 28 in. deep. Three boxes, each with seven compartments, 30 by 30 in. and 36 in. deep, are employed on the weak solution. The waste solution, before leaving the mill, is passed through two zinc boxes of seven compartments each. All the boxes are fitted with side-launders for the delivery of the zinc-gold slimes to the reduction-tank. The gold liquor is drawn off from the top of the tank thoroughly clear, and no filters are required in the zinc boxes.

Sulphuric acid is used for the treatment of the precipitates,

and after a thorough washing and drying they are melted into bars on the premises. The system employed in cleaning up and smelting to bullion is described on page 546.

The Cyanidation.

(*a*) *Double Treatment.*—After the charge has been sampled, leveled, and the requisite quantity of lime (found from acidity test on 100 gms. of pulp) added, the cyanide solution is applied and allowed to percolate through the ore. A copy of the mill diary-notes, taken during the treatment of a charge of tailings, will illustrate the current practice. It is to be understood that the treatment varies as changes in the nature of the ore are manifest.

Charge No. 127. *Vat No.* 5 (upper). *Ore*, 200 *Tons.*

Tons KCN.	Strength of KCN.	Day.	Hour.
30	.07 per cent.	June 9	10 A.M.
20	25 "	" 10	3 A.M.
20	.25 "	" 10	5 P.M.
15	.25 "	" 11	2 A.M.
25	.25 "	" 12	1 A.M.
10	.25 "	" 12	8 P.M.

At 3 P.M., June 13th, the charge was shoveled to the lower vat (No. 5). This required 6 men 8 hours.

Charge No. 127. *Vat No.* 5 (lower). *Ore*, 200 *Tons.*

Tons KCN.	Strength of KCN.	Day.	Hour.
23	.30 per cent.	June 14	1 A.M.
10	.25 "	" 14	3 P.M.
10	.25 "	" 14	11 P.M.
10	.25 "	" 15	8 A.M.
15	.06 "	" 15	10 P.M.
20	.06 "	" 16	11 A.M.
Tons W t r			
20	....	" 17	2 P.M.

The charge was then allowed to drain until 2 A.M., June 18th. The residues, after sampling, were discharged by 10 A.M., June 19th.

Samples taken from the charge during the leaching period showed the following per cent. of extraction:

Day.	Hour.	Per Cent of Extraction.
June 10	3 P.M.	28.6
" 11	3 P.M.	42.4
" 12	2 P.M.	64.8
" 13	2 P M.	74.2

The charge was then allowed to macerate 12 hours with a .30 per cent. KCN solution, and gave extraction as follows:

Day.	Hour.	Per Cent. of Extraction.
June 15	7 A.M.	76.5
" 18	2 A.M.	77.4

A final tailings sample was taken, just before discharging, which showed an extraction (by assay) of 77.25 per cent. The rate of leaching, in the upper vat, varied from 11 gals. to 7½ gals. per minute. It was about 15 gals. per minute in the lower vat (No. 5).

The values, as will be noticed, yield rather slowly to the solvent action of the solution. This is no doubt partially due to small particles of coarse gold, which are apt to be enclosed in the larger grains of sand. The system employed in charging the vats is to fill two of the 100-ton vats at once and the 30-ft. and two 40-ft. vats singly. A good deal of concentration goes on in vat No. 5, and the extraction-percentage is correspondingly decreased. The extraction cited in charge No. 127 is below the average of the 100-ton vat extractions. It is due entirely to the elimination of a great percentage of the slimes, and is very much below the average extractions obtained in single treatment in the larger vats. The percolating solutions from all the vats are regularly titrated for free cyanide, and, when required, for total cyanide, at least once every eight hours, and frequently several times in a shift. The titrations serve as a guide in controlling the treatment of each vat-charge. A few of the titrations made on the outgoing solution from charge No. 127 showed:

At 8 A.M. on the 10th of June, .01 per cent. free KCN and .03 per cent. total cyanide.

At 8 A.M. on the 11th of June, .09 per cent. free KCN and .15 per cent. total cyanide.

At 8 A.M. on the 13th of June, .19 per cent. free KCN and .195 per cent. total cyanide.

The large quantity of double cyanide found in the weaker solutions first coming from the charge is probably due to the nascent HCN, liberated from the action of acid salts uniting with the zincate of potash contained in the working solution, and forming zinc potassium cyanide.

The gold-values in the solution show a gradual rise from a few cents at .005 per cent. test to their maximum value at .22–.24 per cent., again declining to 20–35 cents per ton when the solution falls in cyanide to .03–.04 per cent. when the residues are discharged.

A total consumption of cyanide of from 1 lb. to 1.25 lbs. is found in double treatment; 0.7 to 0.8 lb. is consumed by the cyanicides (chiefly copper minerals), about .125 lb. is discharged with each ton of tailings, and about as much more, per ton of ore, is run to waste out of the mill, the combined gold being removed, in part, by the waste zinc boxes. A small amount is rendered inert, of course, during the precipitation of the bullion in the zinc-extractor boxes, but a portion of the cyanide contained in the double salt of zinc is regenerated, when leaching, as potassium or sodium cyanide. The consumption of cyanide due to zinc precipitation is usually so small that it is scarcely appreciable.

A great deal of cyanide is consumed after the charge has been shoveled to the lower vat, and the solution applied. This is probably due to the oxidation of some of the cupriferous minerals. The consumption in the single direct treatment system is approximately 0.7 lb. per ton, about .35 to .45 lb. of which is due directly to the presence of cyanicides in the tailings; the remainder is lost by dilution and by the discharging of a certain amount with the residues. The lower consumption is solely due to the fact that there is no shoveling, and consequent aëration and oxidation of the baser minerals.

Exhaustive experiments on a large scale have recently been carried out with a view of recovering the cyanide contained in

the waste solutions. It was clearly demonstrated that a large percentage of the free cyanide, and that combined with the zinc, could be recovered with ease and profit, and converted into an effective extracting solution.

The cyanide that combined with the copper could also be recovered cheaply, but, in view of the low chemical consumption obtaining, it was not deemed advisable to install a "Recovery" plant.

(*b*) *Single Treatment.*—The treatment of the tailings is carried on much in the same manner in single as in double treatment. The solution, usually 0.25 per cent. KCN, is kept in circulation for seven or eight days, or until the assays of the samples, taken at regular intervals from the charge, show that an adequate extraction has been obtained. When the vat is filled, care is taken not to drain the charge of water more than is necessary to enable the sampling and leveling to be done comfortably. It seems important to allow the particles of sand to be surrounded with a "water-cushion," which is subsequently displaced by a "solution-cushion." If the charge is completely drained before applying the solution, the sand packs tightly, and subsequent leaching operations are much retarded. No vacuum is employed in either of the systems, as no difficulty occurs in obtaining a good rate of percolation.

An example, illustrating the single treatment, is copied from the mill diary, and the percentage-rate of extraction after certain periods may be of interest.

The charge—No. 267, vat No. 6, 300 tons—was filled at 9 A.M. on Dec. 29, 1901, and, after sampling and leveling and adding the requisite lime, 40 tons of .06 per cent. KCN were applied at noon, and also at 10 P.M. of the same day. A .25 per cent. solution of KCN was then applied, and kept in circulation for seven days, with occasional periods of maceration. The charge was then allowed to remain in contact for 12 hours, drained partially, and weak washes of .06 per cent. KCN, amounting in all to 60 tons, were applied. (The solution washes are run on till the vat is filled to the brim, thus making use of the slight head obtained to aid percolation.) When the weak solution had drained sufficiently, about 35 tons of water were applied, and by midnight of Jan. 8, 1902, sufficient cyanide was removed to allow of the residues being

sampled and discharged. The actual time of treatment was $11\frac{3}{4}$ days, and assays taken from the pulp during that time, at intervals, show the following rate of extraction:

No.	Time.	Per Cent. Extraction. Gold	Silver.
(1)	1 P.M. Dec. 30,	12.40	4.00
(2)	3 P.M. Jan. 1,	53.60	21.20
(3)	2 P.M. Jan. 3,	68.00	42.60
(4)	2 P.M. Jan. 5,	77.50	50.00
(5)	4 P.M. Jan. 7,	85.00	57.00
(6)	12 M. Jan. 8,	85.70	63.00—Final tailings.

The rate of percolation on this vat-charge was about 17 gals. per min. for the first two days, and gradually slackened to from 10 to 12 gals. near the end of the treatment. The total quantity of solution received, including water-washes, was 340 tons, or 1.13 tons per ton of tailings.

Comparison of Single and Double Treatment.

Referring to the grading-tests on page 539, it will be seen that the material settled in the 300-ton vat had a greater fineness than that settled in the 200-ton vats, and was also slightly finer than the material caught in filling two of the 24-ft. vats at once. To this fact may partially be attributed the increased extraction in the single treatment. A comparison of the results obtained on a large number of vat-charges indicates that an increase of 15 per cent. is found in the quantity of leachable material deposited in a given time, and an increase of 5 per cent. in the gold-extraction in 20 per cent. longer time.

At the same time there is a decrease of cost in labor of 9 cents per ton, and in the cyanide-consumption of 10 cents per ton; and, taking into consideration the increase in cost of constructing a plant for double treatment, the advantages of single treatment on these tailings are so obvious that further argument would be superfluous.

The tailings are discharged by sluicing throughout the year. A pressure-pump is used in winter, however, to pump the slimy water from the dam to the hose-line. With a 3-in. hose, $1\frac{1}{4}$-in. nozzle, and a pressure of 60 lbs., one man can discharge 100 tons and clean the filter-bottom in two hours. Bottom-discharge doors are used.

The Precipitation of the Bullion.

The zinc used in the precipitating-boxes is received in sheets, 7 ft. long and 18 in. wide, costing 7.66 cents per lb., and are cut in the machine-shop to a thickness of $\frac{1}{1400}$ in. A Hampton lathe is used, and, winding 5 or 6 sheets on the mandrel at once, a man can cut 140 lbs. per day, about one-half lb. of which is waste. The consumption of zinc per ton of ore treated is .45 lb.; the greater part of this is consumed by the refining process, and but a small proportion is dissolved in the boxes. The cost of cutting the shavings is 2.7 cents per lb., bringing the total cost at the mill to 9.36 cents per lb., or 4.66 cents per ton of ore. The precipitation of the bullion offers few difficulties, and is usually very perfect.* Occasionally, however, when the solution carries much copper, the degree of precipitation will be poorer, especially in the weak boxes, and cases will sometimes be observed when the weak solution has re-dissolved the precipitated gold, running out of the boxes many times higher in value than when entering.

The remedy for this is periodical flooding of the weak boxes with a stronger gold-bearing solution; frequent re-arranging of the zinc in the compartments; and, perhaps, occasionally entirely removing the zinc from the boxes, placing it in the strong boxes, and putting in its place zinc coated with a metallic film of lead or mercury. No effort is now made to prevent the depositing of the copper on the zinc with the gold, as it was found that, when pains were taken to keep the copper out of the extractors, the solutions speedily became overcharged, and eventually the copper would come down in such a strong coating that the bullion was almost if not quite excluded. The overcharging of the solutions with the double cyanide of copper has a most vitiating effect on their dissolving power, and a solution thus fouled will take very much longer to make the same extraction than would a fresh solution; and in some cases the same extraction cannot be attained at all, even with a prolonged contact. A solution fouled in this way is usually very low in its dissolved oxygen-content, and it is probable that this influences the rate of extraction to some extent. A little copper in the solution is undoubtedly a very effi-

* Normally the sumps carry from 1 or 2 grains to 4 or 6 grains of gold per ton.

cient aid in precipitation, and it is only when the copper is allowed to accumulate that difficulties are encountered here in the extractors. The sump solutions usually carry .015 to .020 per cent. copper; and, as long as this is kept fairly constant, satisfactory results ensue. An average of a number of analyses on the incoming and outgoing solutions shows:

	Per cent. Cu.	Per cent Zn.
Strong gold tank solution,	.025	.073
Weak gold tank solution,	.0188	.036
Strong sump solution,	.018	.0745
Weak sump solution,	.017	.037

The solutions, before pumping to the leaching-vats, are aërated for an hour. This raises the dissolved oxygen-content considerably, but, on standing for some time after aëration, some of the dissolved oxygen diffuses in the atmosphere.

Estimations of the dissolved oxygen in the solution at various stages in the process are:

(1) Solution in sump before aërating and standardizing, 2.30 mgms. per liter.

(2) Solution as pumped to leaching-vats after aëration, 7.35 mgms. per liter.

(3) Solution after standing on vat-charge for one hour, 6.80 mgms. per liter.

(4) Solution after leaving the vat at gold tank, 2.22 mgms. per liter.

(5) Solution after leaving the zinc-boxes, 0.82 mgm. per liter.

The weak solution contains about the same amount of dissolved oxygen in all cases except when leaving the zinc-boxes, where it is slightly higher than the strong solution, containing, in several cases, 1.50 mgms. per liter.

Clean-up of the Zinc-Boxes.—This is made monthly. The cyanide solution is displaced by running a stream of water through the boxes, which thoroughly washes the zinc in each compartment; the fine sludge is then screened, sluiced down the side-launders, and settled in the reduction-vat. The remaining zinc is replaced in the upper compartments, the lower end of the box being replenished with fresh zinc, and the solution, strengthened for a few hours with a little cyanide at the head of the box, is again turned in. There is no handling of the valuable precipitates, everything being sluiced by gravity

to the settling-vat. When all the extractors have been deprived of their zinc-gold slimes, the vat is allowed to remain undisturbed for a few hours. The supernatant liquor being siphoned off as closely as possible, sulphuric acid (sp. gr. 1.84, and costing 1.80 cents per lb. at the works) is applied, with constant stirring, till all action ceases. The vat is then filled with water, settled, the liquor siphoned off into a settling-tank directly under the reduction-vat, and a succession of water-washes applied as rapidly as possible, siphoning off as soon as sufficiently clear. The small amount of values contained in the wash-settling vat is cleaned up at long intervals. It is desirable to leave a portion of the sulphates behind, in order that a regulus or matte may be formed in melting. A considerable quantity of the copper is matted off in this way, leaving a comparatively fine bullion.

After washing, the slimes are partially dried on a blanket-filter and removed to a hearth furnace (hearth 6 ft. by 4½ ft.), and subjected to calcination for four hours at a dull red heat. When cooled, the product is transferred as required, mixed with a suitable flux, and smelted in graphite crucibles, in two wind furnaces (20 in. by 20 in. by 28 in.). The flux found to be most suitable is composed of borax, 4½ parts; soda, 2½ parts; carb. potash, ½ part; silica, 2½ parts. The flux is mixed with the calcined precipitates in the proportion of 1 to 2.

No niter is used in the preliminary melt, as it is preferable to combine the base metals with sulphur, rather than attempt to remove them as oxides. The corrosion of the crucibles is also slighter than when niter is used. When the charge is thoroughly quiet and fluid, the slag is skimmed off repeatedly with a drop-forged iron ladle, fitted with a handle bent almost at right angles, to save the attendant from the heat of the fire. The crucible, when sufficiently filled with molten metal, is removed, and the contents poured into moulds. The casts are quickly emptied and thrown into a tub of water, to facilitate the removal of the matte. The latter, in addition to some bullion value, contains about 60 per cent. of copper and a small per cent. of zinc. The bars from the first melt are freed from matte with a few blows of the hammer, and are re-melted in No. 20 crucibles, refined with a little niter and bone-ash, and carefully cast into bars of 500 oz. weight, pickled in dilute acid,

cleaned, and packed ready for shipment. The first pouring is conducted at a high temperature, to insure the ready and clean removal of the matte on chilling. The final melt is, however, poured at a much lower temperature, and the finished bars are very tough and quite malleable. The slag and matte are bagged, and shipped to the smelter.

In a recent clean-up, in which over 5000 oz. of bullion was obtained, 800 oz. of matte was formed in melting, containing .345 per cent. of the total value, and 7200 oz. of slag in which .62 per cent. of the total value was locked up for a time. The average value retained by the matte and slag may be safely estimated at a trifle over 1 per cent. of the value contained in the precipitate.

The matte carries a greater silver value (usually 2 to 1) than gold, while, in the slag, values are about equally divided.

The labor involved in cleaning the extractors, tending acid refining and subsequent drying, calcining and melting, the sulphuric acid used, and the fluxes, crucibles and fuel, cost altogether (on an average of a number of clean-ups) one cent for each dollar in bullion produced.

The total working-costs per ton are given in the following table:

The Cost of Treatment per Ton.

Labor,	$0.2025
Cyanide,	0.2860
Zinc,	0.0466
Lime,	0.0140
Elevation of pulp,	0.0375
Cleaning up, refining and melting, labor, supplies,	0.0437
Sundries: Filters and shovels, etc.,	0.0065
Chemical supervision and assays,	0.0850
Total cost,	$0.7218

These costs are for the combination of single and double treatment at present in vogue here; should all of the mill be changed to single treatment, as is probable, the future working-costs would be reduced 15 to 18 cents per ton, on the same monthly tonnage.

The plant for the treatment of dam slimes is at work during the four summer months, and has a capacity of 60 to 75 tons per day.

Postscript.

(February 20, 1903.)

Since writing the above, a filter-press has been installed to facilitate the cleaning up of the zinc-gold slimes. The press is an open-delivery, two-eyed pattern, with flush-plates and distance-frames, forming a cake 1 inch thick. Each press-charge of twenty-four cakes weighs, when dry, about 350 pounds. The cakes are 19 inches square, and are formed between layers of heavy woollen filter-cloth covered with filter-paper.

During the clean-up of the precipitation-boxes, the liquor in the reduction-vat is continually siphoned into a small sump, and elevated by a Pohle air-lift 5 feet into a *montejus*, and from thence forced by air-pressure through the press, to remove any solid matter. The contents of the press are added to the slimes remaining in the vat, and the mass subjected to treatment with sulphuric acid, with constant mechanical stirring.

When the reduction has been completed, the refined slime and acid liquor is delivered to the *montejus*, and kept, by compressed air, at a pressure of 60 lbs. for two or three hours. This contact under pressure with dilute sulphuric acid removes much of the copper, leaving a very pure product for subsequent melting. The contents of the *montejus* are forced into the press, and the liquor, heavy with copper and zinc, removed; the press-cakes are washed by water under pressure to remove sulphates, and finally partially dried with compressed air. When removed to the melting-room, for drying and melting, the cakes contain about 17 per cent. moisture, and are tolerably free from sulphates.

The filter-press, with the *montejus*, has proved a very valuable aid in the monthly clean-up, rendering the mechanical loss of gold practically impossible, and saving considerable time.

The writers are in receipt of "The Camp Bird Gold Mine and Mills," by Mr. H. A. Titcomb, reprinted from the *School of Mines Quarterly*, New York, November, 1902. It is regretted that this publication was received too late for detailed reference in the body of this paper.

Puddled Iron and Mechanical Means for its Production.

BY JAMES P. ROE, POTTSTOWN, PA.

(New York and Philadelphia Meeting, February and May, 1902.)

STEEL has occupied such a prominent position in most minds during the last thirty years, particularly since the introduction of the basic open-hearth process (by which the field from which the raw material could be obtained has been so widened), that little attention has been made to improvements in puddling iron. In fact, the general tendency seems to have been to accept the prediction that puddled iron is doomed. Events have in a measure justified such a forecast, due in large part to the introduction of mechanical appliances and operations with large units in the manufacture of steel, from which much lower costs have resulted. But this general tendency has met checks in certain directions. This is notably the case where the finished product is a welded one, or is subject to oxidation, to shock or to vibration; and, as far as the writer's observation goes, the bond (which is largely a mechanical one) is not as close and lasting between steel and tin or zinc as between iron and the same materials. The field still open for puddled iron is, therefore, a large one, provided the low costs of steel-manufacture can be approached.

The process of puddling is one of the most interesting in the metallurgy of iron, as the reactions and the changes effected are apparent. The subject has had the strongest fascination to the writer from boyhood, and has led, not unnaturally, to a close study, which long ago resulted in the conviction that it could be successfully carried out with large units and by mechanical means. That others have also drawn these conclusions is shown by many undertakings, though there have been few such attempts during the last twenty-five or thirty years.

Puddling consists, essentially, in the removal of most of the carbon and silicon, and part of the phosphorus and sulphur

from pig-iron by agitation, while molten, in the presence of suitable cinder and gases of the right composition and temperature. These are, broadly, the conditions up to the period of balling, which final operation will, of necessity, differ when carried out by manual or mechanical means.

The process developed by the writer is being carried out in the machine or furnace illustrated by Figs. 1, 3 and 4.

The general framing consists of two side-plates, suspended from a trunnion on each side, carrying the whole machine, and these trunnions rest upon roller-bearings supported by an elevated framework. The side-plates are extended underneath, forming segments of circles, to which the operating-racks are secured. These gear into pinions driven by a reversing-engine. Between the side-plates are four distance-pieces, which form girders from one trunnion to the other. The stack-bases and the angles under the bottom also serve both to form part of the framework and to strengthen it.

The bottom, consisting of a series of water-cooled parts, rests upon the angles referred to and supports the working-bottom of magnesite brick. This material is also used to line the end and sides, up to the wash-line of the cinder; the sides above the cinder-line, the roof, and the lining of the four stacks being built of fire-brick.

At present, the furnace is fired by means of crude oil and blast; but coal or gas can be used, should convenience or economical reasons require it. Oil was adopted in the present instance on account of convenience of application and ease of regulation. The fuel is introduced through the two trunnions, which form efficient combustion chambers, and the flames directly impinge on each other at the middle line of the furnace, thus producing a most intense and thorough combustion. The flames then pass to the four converging stacks, two of which are at each end of the furnace, and by this means a complete filling of the chamber is assured.

The whole of one end of the furnace is closed by a door, built up of removable sections, and suspended from a shaft running across the furnace. The door is opened and closed by two side connecting-rods, which connect the bottom girder of the door to a cross-head operated by a hydraulic cylinder under the furnace. Parallel motion in the cross-head is assured

by means of pinions at each end, engaging in racks fastened to the side-plates of the machine. The closed door is locked by means of wedges, operated by hydraulic cylinders, which pass through the side-plates and the connecting-rods. The wedges also aid in making tight the joints of the door.

The top-, bottom- and side-edges of the door are made with a $\frac{1}{8}$-inch radius in order to crush and grind out any cinder left on the sill, lintel or jambs at the time of discharging the ball. The sill and lintel are formed with water-cooled convex surfaces (extra heavy pipe), to chill the cinder in making the joint before charging, and to make it crush and part more easily when the door is closed after discharging.

The bottom is rectangular in plan, being about 20 ft. by 8 ft. 8 in. in the clear, while the sides and ends are straight and stand at right angles to the bottom. The form of the furnace is, therefore, the simplest possible, and the one which is the most easy to maintain. The high roof in the middle gives room for flame development. It slopes down, to direct the flame against the bottom, and rises again to allow sufficient space for the wash of the bath at the ends.

The machine can swing through about 65 degrees on each side of the center line of the trunnions. It is, therefore, a puddling-furnace in which the necessary agitation for producing an intimate mixture of the molten metal and oxides is obtained by allowing them to run down-hill, first in one direction and then in the other, and suddenly arresting them at the bottom. The subsequent balling of the iron, when it has come to nature, is produced by precisely the same means.

It has been sought to embody in the present effort, as far as possible, the general practice in steel-works; since there is but one period in the production of iron (that from the beginning of crystallization to the squeezing of the mass) where the change from pig-iron to wrought is necessarily different from that to steel.

The bottom, sides and ends of the furnace, being formed as described, are intended to possess relatively permanent characteristics, thus differing radically from the cinder bottom and sides, fixed with ore, from which much of the cinder necessary for puddling is obtained in the ordinary furnace. It is necessary, therefore, to charge into the puddling-machine, as an

equivalent, molten cinder which is melted in an auxiliary furnace designed for the purpose. The tap-cinder from the ordinary furnace is used for this purpose, and is not an active puddling-agent. It serves principally to seal the door-joints; cover and protect the bottom in a measure; to present a medium for retaining the phosphoric acid; to form a lubricant as the iron comes to nature and is massed; and, finally, to act as a welding-cinder in the ball. Roll-scale is added during the process, to act as the principal puddling agent.

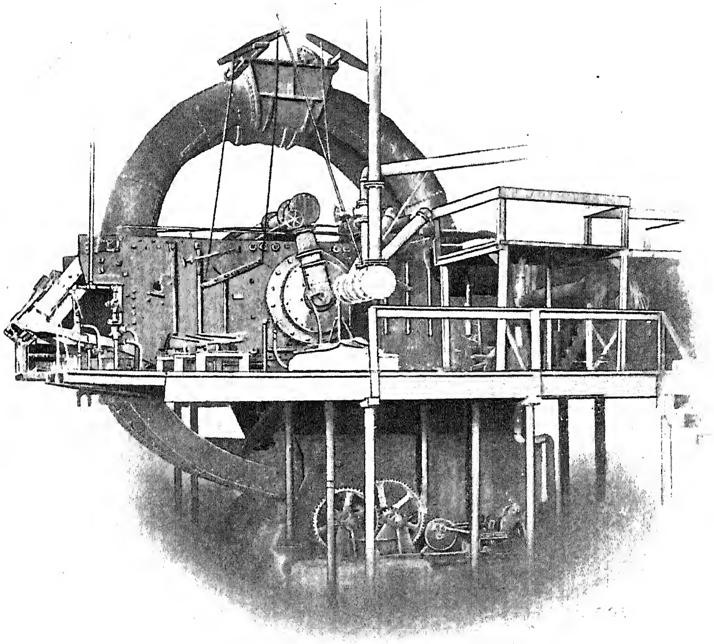
It is intended to use molten iron from a blast-furnace by charging it into a mixer, and drawing the iron from that as needed by the puddler. At present a cupola is used. This latter, however, is open to two objections: greater cost and increased difficulty in obtaining low sulphur.

The molten iron (in the existing machine varying from 3000 to 4000 pounds) is poured through the charging-hole immediately after the cinder, and as soon as the iron is charged the machine is oscillated two or three times. Then the oxidizing agent (roll-scale or easily reduced iron-ore) is added by means of a long spoon (made of a piece of pipe, cut in two longitudinally), which is run in through one of the end peep-holes, given half a revolution and withdrawn, thus evenly distributing the scale through the bath. This is continued between oscillations until sufficient scale has been added. This stage is indicated by free iron ceasing to run on the bottom, or the bath rising for the high boil. This latter is much more active than in an ordinary puddle-furnace. Large volumes of carbonic oxide are emitted, which burns above the surface of the bath to carbonic acid, materially raising the temperature of the furnace and the bath without additional fuel. During the periods of scaling and boiling, as the bath descends the inclined hearth, it is thoroughly agitated and uniformly mixed: in part, by the lower strata being retarded by friction on the bottom, thus allowing the upper strata to flow over the lower; and, more largely, because, as the direction of the bath is suddenly arrested at the end, it turns over upon itself precisely as an ocean wave does.

As the iron comes to nature and thickens, the progress down the hearth from end to end becomes slower, so that the clusters pass slowly through the zone of highest temperature and

acquire the heat necessary for thoroughly welding the whole together in the ball. This massing, or balling, is accomplished by increasing the angle of the hearth so that the mass slides with sufficient momentum to compress and solidify itself. This mass, or ball, has a length about equal to the width of the machine, a width of about 3 ft. 0 in., and a height of 24 to 30 in. When the balling is completed, the side-rod wedges are

FIG. 1.



General View of Roe's Puddling-Machine.

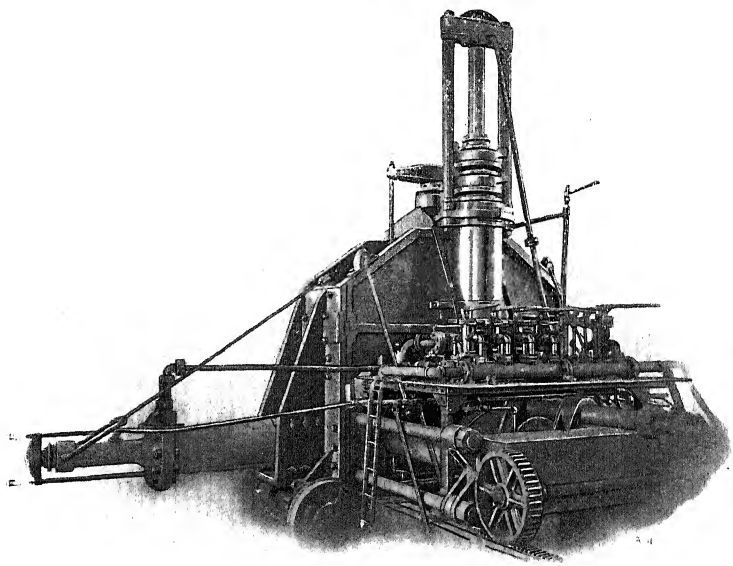
withdrawn. As the front end of the machine descends, the door is opened and the mass is discharged by gravity directly into the squeezer. Any free cinder that may exist is discharged ahead of the mass, and falls in front of the squeezer. The door is then closed and locked, the cinder is poured in, and the machine is ready for the next heat.

Before following the puddled mass further, it is desirable to call attention to the squeezer.

The coffee-mill squeezer is almost universally used to-day, in conjunction with the ordinary process of puddling iron and working with balls weighing about 180 pounds. Although it is in this case probably as effective a mechanical device for a given end as was ever designed, it is not equally well-fitted for handling masses now weighing 4000 pounds, and which, in the future, probably will weigh 10,000 pounds, since the product sought is to be of square or rectangular section.

Hence a special squeezer had to be designed to meet the

FIG. 2.



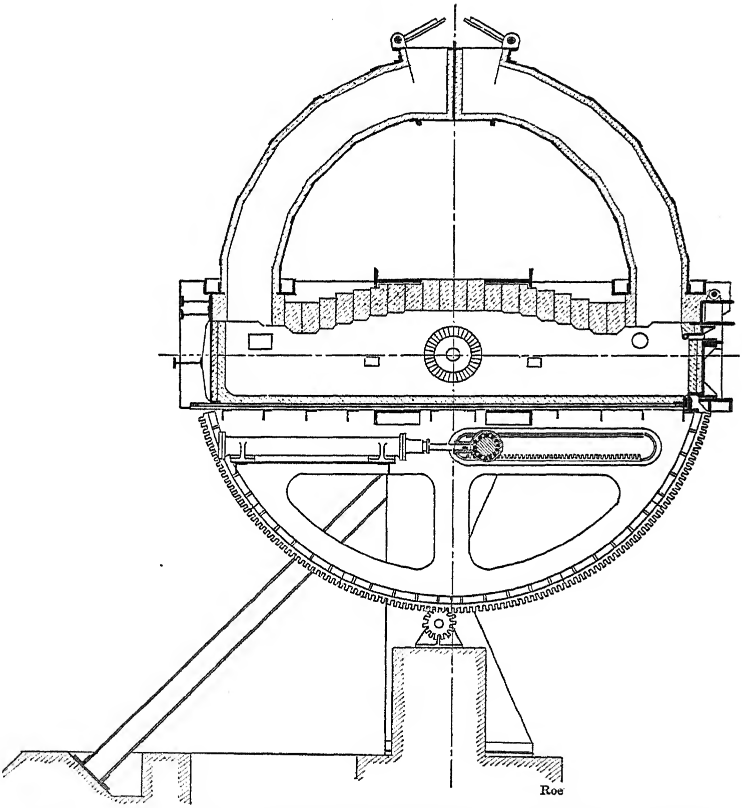
Rear View of Hydraulic Squeezer.

conditions, and it took the form shown in Fig. 2. Hydraulic power was selected. The pressure is applied in one horizontal direction, by means of a front girder operated by the cylinder in the rear; and, at right angles to this, it is applied by means of the two end-cylinders. At present the bloom has a fixed length of 54 in. and a width of 24 in. The vertical pressure is applied by means of the top-cylinder. In order to increase the final pressure, an intensifier is mounted on the squeezer, which raises the pressure from the initial 600 pounds to 2500 pounds per square inch, thus giving a pressure of 1800 tons on

the top area of the bloom. All of the facing-plates which come in contact with the mass are sectional, and have spaces between them for the egress of the cinder as it is squeezed out of the bloom.

The return motions of the various parts are effected by

FIG. 3.



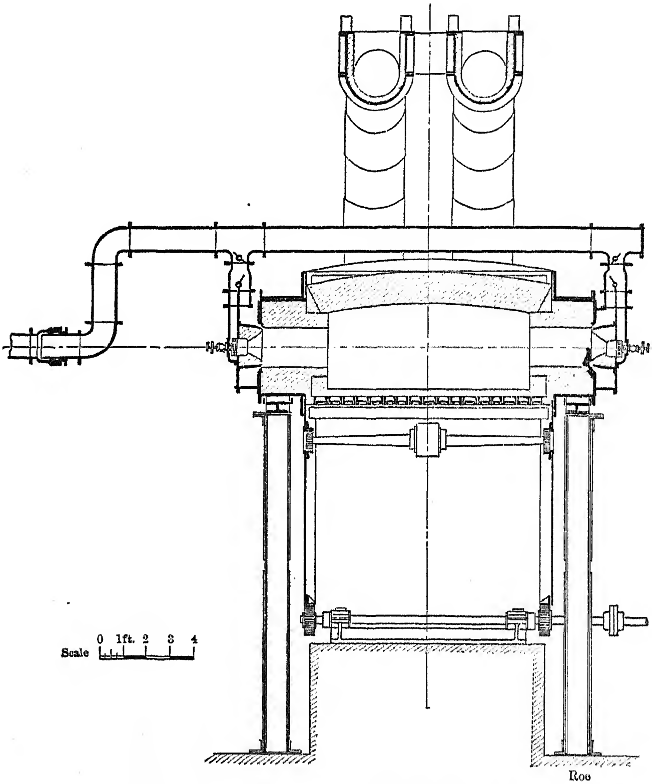
Longitudinal Section of Roe's Puddling-Machine. Scale same as Fig. 4.

smaller hydraulic cylinders, and, by similar means, the bloom is pushed from under the head-piece to the open front.

The whole is mounted upon four wheels, which run on rails extending in front of and parallel to a series of puddling-machines. One squeezer, therefore, would take the balls from all the furnaces and deposit them at a point convenient to the blooming-mill.

The specific object in having a movable squeezer is to avoid any delay at this important period, as it is vital that the iron shall be put together before the projecting clusters cool. Besides this, rapid oxidation takes place when the ball is exposed to the atmosphere, thus causing a loss, and producing an infusible oxide, which tends to prevent welding and a thorough removal of the cinder.

FIG. 4.



Cross-section of Roe's Puddling-Machine.

The squeezer has proved very effective in shaping and solidifying its product. There has been some trouble in freeing all of the blooms from cinder; but, judging from the number which have been so freed, and from the fact that the trouble is not in an aggravated form in any, it is believed that, by giving the cinder more freedom for egress, the result will be fully as satisfactory in this direction as in the others. All the opera-

tions on the bloom, after it has left the squeezer, are identical with those now applied to steel, thereby extending the economy of production to the finishing-mills.

Comparison seems so essential to many conclusions that it is almost necessary to point to some features in the Cort process, as improved by Rogers, in order to obtain a just conception of the present effort.

The conditions throughout the bath, or heat, in manual puddling, lack uniformity. This is recognized by all practical puddlers when they select a bar for testing. This lack of uniformity is cured, in a large measure, at the finishing-mills by piling the good, bad and indifferent together, thus producing a mean that meets requirements. Hence, apart from the inability of manual means to furnish a mass of sufficient size to finish direct, the product so made would vary so much that the proportion of inferior material would condemn the whole. On the other hand, the product of the machine under discussion is relatively uniform throughout a given heat, and is, therefore, well-fitted to roll directly into a finished product. This can be done, provided there is work enough, that is, a sufficient number of reductions in section from the squeezer-bloom to such product. The samples of iron plates and an etched section of squeezed puddle-ball, made by this proccss, go far to combat the usual statement that repeated working and heating of iron is necessary to produce a good product. This statement is illogical. It is impossible to conceive that there can be any inherent virtues in a second or third heating and piling, other than accomplishing something that had not been done in the prior heatings.

The requirements in the material for good results in rolling or forging iron or steel are homogeneity, mass enough to give opportunity for the necessary work (reduction of section) and to retain the temperature, and pressure enough (heavy and effective machinery) to accomplish the desired end before the heat is dissipated. This has been confirmed in modern steel production.

The puddler and squeezer, although presenting some of the shortcomings inevitably associated with being the first of their kind, have, in the main, fulfilled their mission of development satisfactorily, as is shown by the following summary of results in conjunction with the samples obtained.

The pig-iron used has varied in composition as follows:

Sulphur, ...	0.03 to 0.26 per cent.
Phosphorus, ...	0.50 " 1.35 "
Silicon, ...	0.60 " 1.40 "

Many of the heats have shown a satisfactory elimination of phosphorus, and, as was to be expected, this elimination has been found to depend upon the composition and condition of the cinder and the manipulation of the bath during the period before the iron comes to nature.

Some elimination of sulphur has been shown, but, as a general rule, this element should be kept as low as possible in the iron charged. Those heats which have been made with iron taken directly from the blast-furnace have shown the special advantage of such a practice in this respect. The cinder used has a normal composition of about sulphur 0.30, phosphorus 1.73 and silica 20 per cent. Ordinary roll-scale was used for the additions.

The weight of pig-iron charged has generally been between 3000 and 4000 pounds, although some heats as low as 2500 pounds have been made. The average is 3500 pounds.

The weight of cinder has varied considerably. It has been found that about 500 pounds per ton of iron (22 to 25 per cent.) is the proper amount. The amount of scale used has run from 350 to 550 pounds and depends entirely upon the individual characteristics of the heat, such as the character of the pig-iron, the temperature of the bath, etc., just as it does in the ordinary process.

The time required to make a heat has, of course, varied very much, especially at first, running from 24 to 102 minutes. The average duration is 48 minutes, but it is believed that 40 minutes for a 4000-lb. charge will be the average under regular running conditions. This would mean from 15 to 18 heats per turn of 12 hours, or a product of from about 27 to 32 tons of rolled slabs or blooms.

While some heats have shown a loss, and others a gain, between pig and slab, the indications are that the weight of the rolled slab will be about equal to that of pig-iron charged, or will only slightly exceed it. The loss from slab to finished plate, however, runs from 5 to 6 per cent., thus slightly exceed-

ing that of steel, the difference being due to the iron being heated to a higher temperature. The difference in finishing-loss is, however, more than compensated for by the fact that all of the iron made is in the slab, there being no crop-ends, such as are necessary when steel-slabs are rolled from ingots. The loss from pig to finished plate, when using the ordinary puddling-furnace and piling muck-bar, is about 16 per cent.

The physical tests made on this material show better results than those from plates of similar analysis made from ordinary puddled iron. For instance, the samples obtained from plates containing sulphur 0.016, phosphorus 0.10 and carbon 0.05 per cent. give an ultimate strength of 51,000 pounds per square inch, with an elongation of 24 per cent. in 8 inches; while that from a plate containing sulphur 0.019, phosphorus 0.13 and carbon 0.10 per cent. gives an ultimate strength of 62,000 pounds per square inch, with an elongation of 23 per cent. in 8 inches. The latter is a material which may again open to iron the large field of shipbuilding. The above results, together with the entire absence of blisters, show the high grade of product obtained.

It is, of course, somewhat difficult to estimate the probable cost in a properly organized plant from data obtained in working a single machine under experimental conditions; but the indications are, and it is confidently believed, that slabs and billets, and probably the finished product, will be produced at a cost not exceeding that of ordinary steel.

The Original Southern Limit of the Pennsylvania Anthracite-Beds.

BY BENJAMIN SMITH LYMAN, PHILADELPHIA, PA.

(New York and Philadelphia Meeting, February and May, 1902.)

THE question of the original extent of the anthracite-beds of Pennsylvania has often been raised; and even discussed with reference to the probability of their present existence under the New Red, a matter of immense practical importance. So high an authority as my revered master, J. P. Lesley, Honorary

Member of our Institute, has repeatedly supposed that they once extended over a great part of the southeastern corner of the State, at least over the Azoic core of the South Mountain range, and, say, as far southeast as Trenton, N. J.;* yet (on the occasion of his last attendance at a meeting of the Academy of Natural Sciences), he argued unanswerably against the smallest probability of their present existence beneath the Mesozoic rocks of that region. But, notwithstanding his supposition as to the original extent of the anthracite, he would be the last man to maintain that the question is beyond further discussion, or to admit, what some exacting spirits seem occasionally to have believed, that our State geological surveys ought to have discovered by this time every geological fact and the complete solution of every geological problem within their field. No man would more generously welcome additional light upon such matters, even if the result should not altogether corroborate his former views. It is in emulation of his spirit, and without the slightest trace of a contentious inclination, that this paper is presented, in the hope that he may find opportunity to correct, however briefly, any error in its statements, logic or conclusions.

Lesley urges† that the occurrence of No. III. (Hudson river) slates at Limeport, in the South Mountain region, is of great importance, as going to show that the erosion of that range began after the Coal age. He seems soon to have become somewhat less strongly inclined to that view; for a few months later he says, with less positiveness, that "the existence of patches of No. III. slates, overlying the limestones south of the gneiss mountains, . . . suggests that perhaps the entire series of Paleozoic formations, including the Coal-measures, extended continuously far to the south of their present outcrop-lines."‡ Do not these patches seem rather to prove merely that the erosion began after the deposition of No. III., quite in agreement with the indications of the topography and other circumstances?

It seems, indeed, possible that the topography of the southern region, the pebbles of the Pottsville Conglomerate, and perhaps

* *Second Geol. Surv. of Pa.*, 1883, *AA*, p. xxi.

† *Second Geol. Surv. of Pa.*, D^3, vol. i., p. xi., May, 1883.

‡ *Second Geol. Surv. of Pa.*, D^3, vol. ii., p. vii., October, 1883.

the geological structure to the south, may all indicate that the anthracite field never extended far to the southward of Sharp Mountain, and, at any rate, not south of the Lehigh river.

1. In his memoir on "Five Types of Topography,"* Lesley pointed out the striking difference in topographical form of five regions between Cincinnati and the sea, giving, in illustration, a shaded topographical map of an area southward from Pennsylvania. His topographical map of Pennsylvania shows four of the five kinds of topography. The two northwestern types, of the "blue grass" country and the great Cumberland-Alleghany-Catskill, or Western Pennsylvania, plateau, and the southeastern tidewater type do not concern our present purpose. But the decided contrast between the two others (as seen in the map of eastern Pennsylvania herewith reproduced) may have a bearing upon our question. The southern one of these two includes the South Mountains in Adams county, and northward, and the Reading and Durham Hills; and he describes it as the "Blue Ridge, Highland and Green Mountain belt, full of short, sharp ridges, in parallel order, but echelon arrangement, with irregular summit lines, rising into knobs and peaks from 3000 to near 7000 ft. above the sea." The great limestone valley seems to belong with this region, being, however, by reason of the greater softness of its material, destitute of mountains. The space covered by the New Red in Bucks and Montgomery counties, and southwestward, appears to have been also a part of this region, and low for the same reason. The next topographical region northwestward, including the anthracite and other coal-fields, he calls "the belt of the Appalachians, composed of interminably long and narrow barrow-mountains, with level summits, seldom 1000 ft. in height, looped and goffered in an intricate and artificial style, with lens-shaped coves in the northern part; and on the other hand, in the Southern States, terminating in pairs of perfectly straight ridges, cut off short by faults."

The difference in topography of the two regions must clearly be occasioned by the unlike composition and unlike geological structure of the rock-beds, and by the unequal length of their exposure to erosion.

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* *Trans. Am. Phil. Society*, vol. xiii., May, 1866, pp. 305–312.

The rocks of the more southeastern of the two regions are highly metamorphosed, and therefore, in general, very hard, firmly coherent and not easily eroded, compared with the rocks in the northwest. The higher metamorphism appears to be the result of stronger and longer-continued horizontal compression, caused by the shrinking of the earth's crust in cooling. The compression has abundantly produced very steep and overturned dips, and extremely numerous fractures, joints and fissures, promoting the easy circulation of water and the consequent progress of metamorphism, and, in many cases, the cementing of the particles together again by the strongest siliceous binding-material. The resulting hard rocks are eroded much more slowly than the less fully, or not at all, metamorphosed rocks of the more western region, and a merely equal elevation of the hills of the hard materials would consequently indicate a longer exposure to erosion; while greater elevation would be the natural result of the greater height to which the rock-folds have been raised by the stronger and longer, or more frequently repeated, compression. The generally shorter length of the ridges of the southeastern region may come partly from the fact that the strong compression and fracturing has made it possible in more numerous places for the streams to cut across the ridges; but the greater number of such crosscuts or gaps seems still more to be the result of a longer time during which the erosion has been going on. It appears, then, that the rocks of this southeastern region, compared with the next northwestern one, have been longer undergoing compression, have been thereby more strongly compressed, and metamorphosed and hardened, and have repeatedly had the tops of their folds raised to greater elevation, and yet, in great part, reduced again by erosion to nearly about the same height as the northwestern mountains, and to a somewhat more gently rounded shape; so that the erosion must have taken a vastly longer time, and, consequently, the resulting forms have the appearance of greater age than those lying to the northwest. It seems probable, therefore, that this region was already dry land, subject to erosion, while the later portions of the Paleozoic were still forming in the yet undisturbed northwestern region, of which the coal-fields are now a part.

2. Again, the pebbles of the great Pottsville Conglomerate,

at the base of the Coal-measures, are so thoroughly rounded and waterworn as to make it evident that, hard as they are,

A Topographical Map of Eastern Pennsylvania.
Copied from the Map by J. P. Lesley in Report Z, on the Terminal Moraine, State Geological Survey of Pennsylvania. Scale, 30 miles to an inch.

they must have been carried down streams for a great number of miles; and therefore that the sea-shore must have been well to the north of their source. On the other hand, the rapid

diminution in size of the pebbles, northward and northwestward from the southern edge of the anthracite-field, and the quickly increased coarseness of the pebbles at the southern edge, show that the shore of the Carboniferous sea, which laid them down, must have been near at hand and not far south of Sharp Mountain, the present southern boundary of the coal, the line of steep ridges close south of Pottsville and Mauch Chunk. As the diminution in size of the pebbles and in the thickness of the beds is radial, and not from one point alone, but several rather distant ones, the pebbles must have come into the sea at several points; that is, must have come down rivers, with large accumulations near their mouths; and so could not, in any case, be the result of sea-shore erosion along numerous almost continuous cliffs. The sand and shales also seem to have come from rivers. The pebbles, then, indicate that the original southern edge of the anthracite-region could not have been far south of Sharp Mountain, or, at any rate, not farther south than the lower part of the Lehigh valley.

3. One more fact may perhaps be urged as further evidence of the separate and unequal compression and folding, uplifting and erosion of the two regions. The (to say the least) not improbably Paleozoic, Permian, age of the lower part of the New Red of Bucks and Montgomery counties has already been pointed out,* making beds there to appear contemporaneous with beds in West Virginia and the southwestern corner of Pennsylvania. These western beds have partaken of the folding of the main Appalachian region; but the Montgomery county ones have apparently never been disturbed, except by the gentle tilting, uplifting especially the southern border, that has taken place since the deposition of the New Red. It seems, therefore, as if this southeastern region had not been affected by folding at the time when, after the end of the Paleozoic, the anthracite region was strongly crumpled.

It appears probable, therefore, that the anthracite-region never could have extended far south of its present limits; that broad highlands originally bounded it on the south, supplying the pebbles, sand and shales that formed the Coal-measures; that these highlands emerged from the sea at some time before

* *Proc. Am. Phil. Society*, vol. xxxiii., p. 9 (Jan., 1894), and p. 215 (May, 1894); also, *Final Report Second Geol. Surv. of Pa.*, vol. iii., part ii., p. 2614.

the end of the Silurian epoch (say, after the deposition of No. III., the Hudson river slates); that by strong and long-continued compression they became highly metamorphosed, and had their rock-folds repeatedly raised higher; and that they have been eroded for a much greater length of time than the anthracite-region and the rest of the main Appalachians.

The Veins of Boulder and Kalgoorlie.

BY T. A. RICKARD, DENVER.

(New Haven Meeting, October, 1902.)

COMPARISONS frequently do good service by affording a means of distinguishing the features which are essential from those which are merely accidental. When one reads of the lode-structure of a new, and perhaps distant, gold-field, there arises the desire to compare the characteristics mentioned with those of the regions with which one is already familiar. It will therefore be interesting to refer to the other districts with which Cripple Creek has been likened.

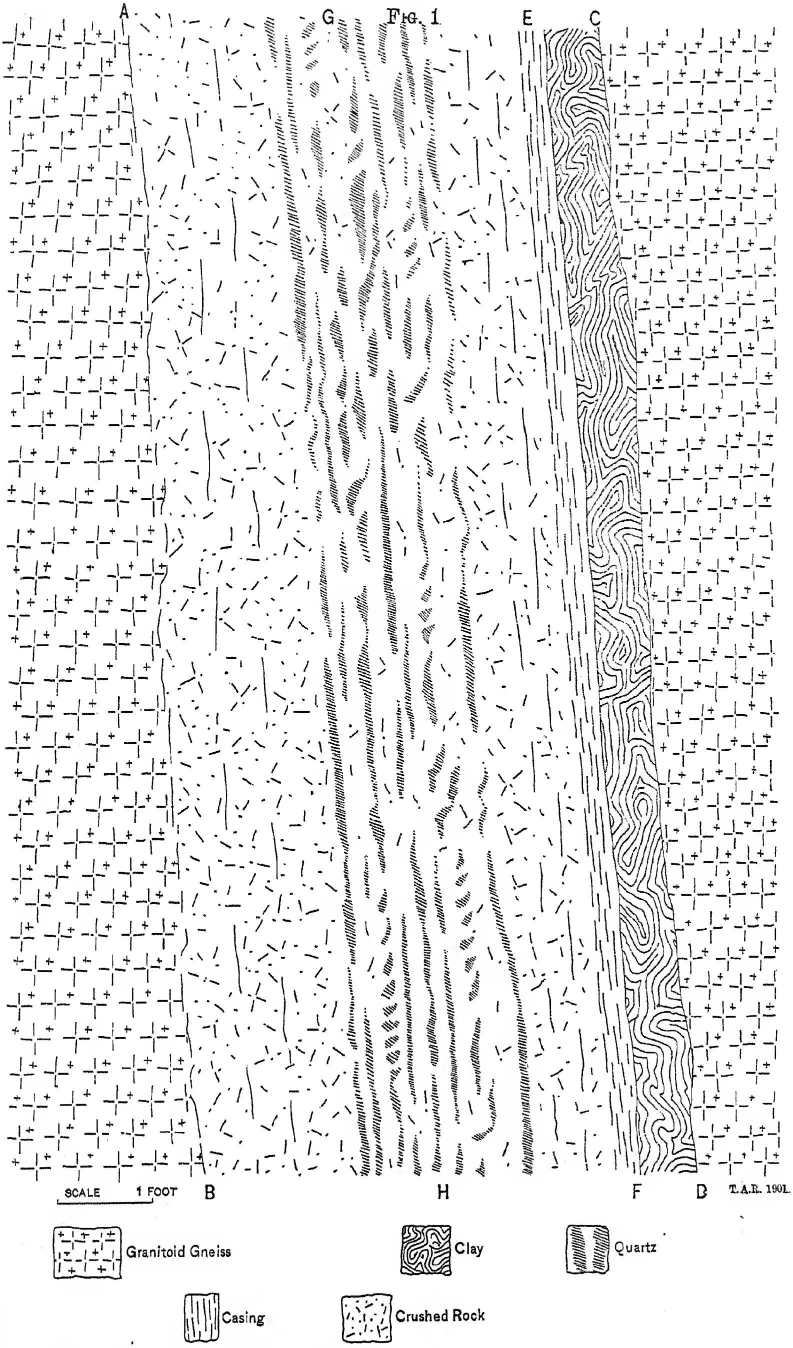
A. THE VEINS OF BOULDER COUNTY, COLORADO.

Telluride-ores have been mined in Colorado since 1872. Previous to 1891, when Cripple Creek was discovered, the principal localities for such ores were the La Plata mountains and Boulder county. The former district is situated in the extreme southwestern part of the State. Boulder is about 90 miles due north of Cripple Creek, in that part of Colorado which was first opened up by the pioneers of 1859. The prevailing rock is the granite-gneiss of the Front range. The veins are notably associated with bands of chloritic gneiss, to which the French geological term of "protogine" was formerly applied. Dikes of quartz-porphyry and quartz-andesite occur at frequent intervals. In this respect Boulder resembles the adjacent well-known district of Gilpin county, but the ore-occurrence does not appear to be as intimately connected with the dikes as it undoubtedly is in Gilpin.

The veins of Boulder appear to be bands of crushed rock accompanying lines of fracture which have been healed by the impregnation of ore. Fig. 1 will illustrate this characteristic type. The Enterprise is the principal lode of the El Dora district, on the western border of the county. The enclosing formation is granitoid-gneiss, traversed by belts of protogine and mica schist. In this instance a band, 8 inches thick, of clay, called "gouge" by the miners, and consisting of rock crushed to the condition of mud, follows the hanging-wall, which appears as a distinct parting, separating the lode, A C, B D, from the enclosing country-rock. Next to the "gouge" comes a well-defined strip, 3 to 4 inches wide, of casing, which is made up of brecciated gneiss so laminated as to resemble a shale. The foot-wall is not very distinct, because the lode-matter merges insensibly into the country-rock. The ore, G H, appears in the form of dark threads of flinty quartz arranged in parallel lines amid the lode-stuff, which is essentially a granular matrix of partially-crushed granite-gneiss. The dark quartz carries finely-disseminated tellurides, chiefly petzite, which renders a width of 2 to $2\frac{1}{2}$ feet sufficiently rich to yield an average of 2 ounces of gold per ton.

The Monongahela vein, shown in Fig. 2, occurs at Sunshine, in the central part of Boulder county, and resembles a score of similar lodes to be seen in the small mines which yield the bulk of gold from this interesting region, and are intermittently worked under lease by parties of experienced miners. Fig. 2 represents the eastern face of the 100-ft. level in the Monongahela workings as seen in April, 1897. The most prominent feature of the section is a dark band (A E, C H) of "hornstone," or flinty quartz, which, on closer examination, is found to be composed of two separate streaks, A F–C G and F E–G H, in both of which specks of petzite are clearly distinguishable. The upper portion, 3 inches wide, has numerous cavities, "vughs," lined with crystalline quartz and marcasite (white iron pyrites). The lower one, $2\frac{1}{2}$ inches wide, is more compact. Between the pay-streak (A E, C H) and the foot-wall (B D) there is a thickness of 7 inches of dark-gray quartz, through which patches and streaks of granular protogine are distributed. This band carries only traces of gold. It marks

FIG. 1



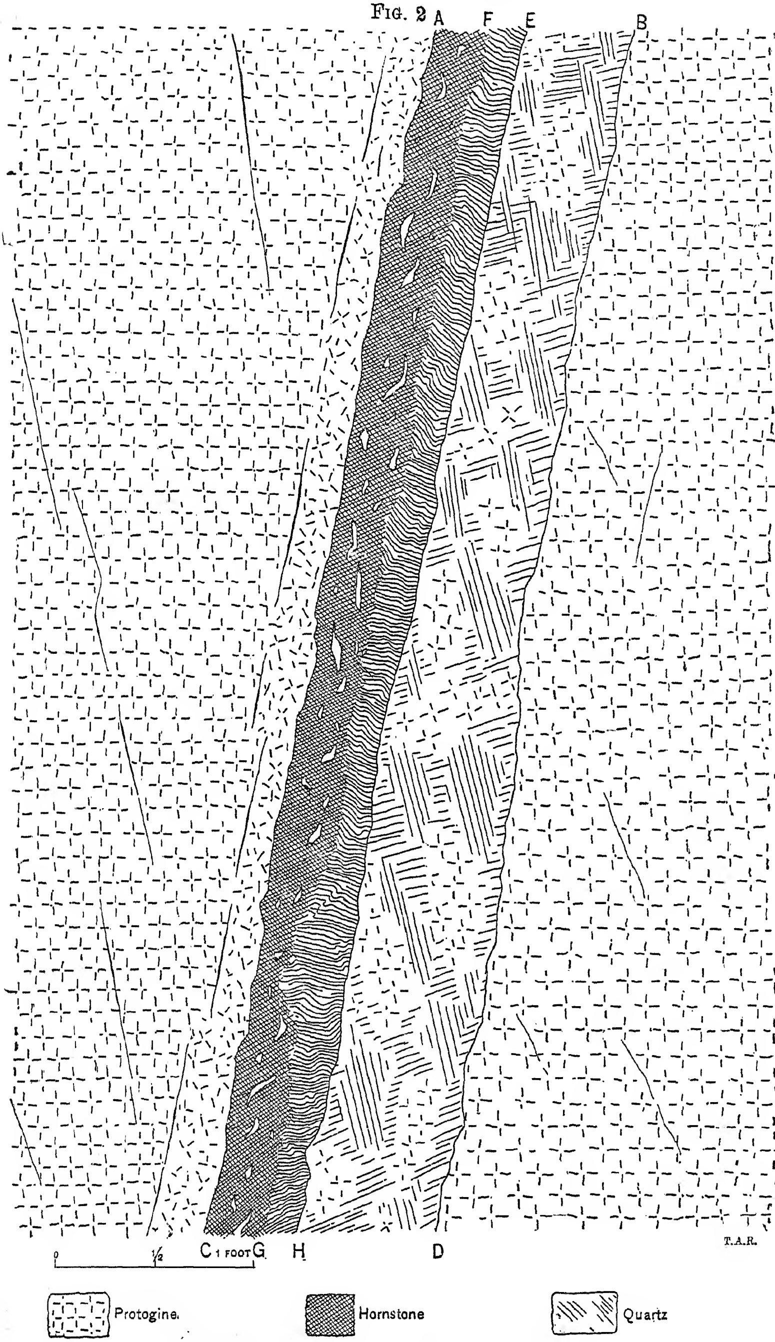
ENTERPRISE VEIN. EL DORA, COLO.

the transition between ore and country-rock. There is no distinct hanging-wall. A narrow width of crushed country, A C, separates the pay-streak from the enclosing rock. The latter is traversed by several dark threads of flinty quartz, which may be regarded as feeders to the vein proper.

A little further west the pay-streak splits into two dark filaments of hornstone, separated by mottled quartz, and the lode becomes more valuable. This change is illustrated in Fig. 3. The band (E B, H D, in Fig. 2) of quartz containing inclusions of country-rock has thinned out, and finally disappeared. The double streak of ore (A F–C G and F E–G H in Fig. 2) has separated into two threads (E K and F L in Fig. 3) of banded hornstone, containing frequent cavities lined with quartz-crystals. Between these two threads there is a width of 5 inches of dark mottled hornstone, containing tellurides, and forming, therefore, rich ore. The small thickness, A C, of altered country to be seen on the hanging-wall side in Fig. 2 has become amplified in Fig. 3 to a 3-inch casing, C G, of crushed rock, and a further width, D H, of 6 inches of breccia, consisting of fragments of protogine cemented by brown quartz. The lode, which may be considered as extending from C to F and from G to L, is in protogine, and consists of that rock in variously altered condition, graduating from crushed country-rock, C G, to crushed rock impregnated with quartz, D H, and finally into a clean, dark, siliceous matrix, E F, K L, to which the term "hornstone"* can be fitly applied. The nature of the ore-occurrence can be further inferred from the gold-contents of the various portions of the lode. Thus, C G was poor, that is, it contained $\frac{1}{10}$ of an ounce or so of gold per ton; H D carried 8 ounces of gold per ton; and the main streak, E F, K L, was worth, at the time of my visit, from $2.50 to $5 per pound. The band H D becomes at times so impreg-

* The miners, by evident confusion, called the dark, flinty veinstone "hornblende," instead of "hornstone," and in the same manner they had converted "vugh-hole" into "bug-hole." Hornstone is good Anglo-Saxon, horn meaning resembling horn in being callous or hard, as in "horny-handed son of toil." The word "chert" is nearly a mineralogical equivalent for hornstone. Chert is Irish, and originally meant "pebble."

FIG. 2



MONONGAHELA VEIN, BOULDER COLO.

nated with dark quartz as to merge into the main streak of ore.

There is no selvage separating the ore-streak, E F, K L, from the enclosing rock. The seam of black hornstone, F L, is "frozen" to the foot-wall. This "hornstone" is a characteristic feature of the telluride-bearing streaks of Boulder county. It is essentially massive, compact silica, otherwise chalcedony or flinty quartz, darkened by the presence of finely disseminated particles of iron pyrites (chiefly marcasite) and the tellurides of gold and silver (either petzite or sylvanite). The richer portions are frequently characterized by the presence of prochlorite and roscoelite. The latter, which is a vanadium-mica, of a brownish-green color, is so notably associated with the valuable ores of Boulder that the miners have got into the way of considering it an essentially gold-bearing mineral. It occurs in the lodes of Kalgoorlie, in West Australia, and quite recently it has been found in the "Last Dollar," "Mary McKinney," and other mines in the Cripple Creek district.*

B. The Lodes of Kalgoorlie, West Australia.

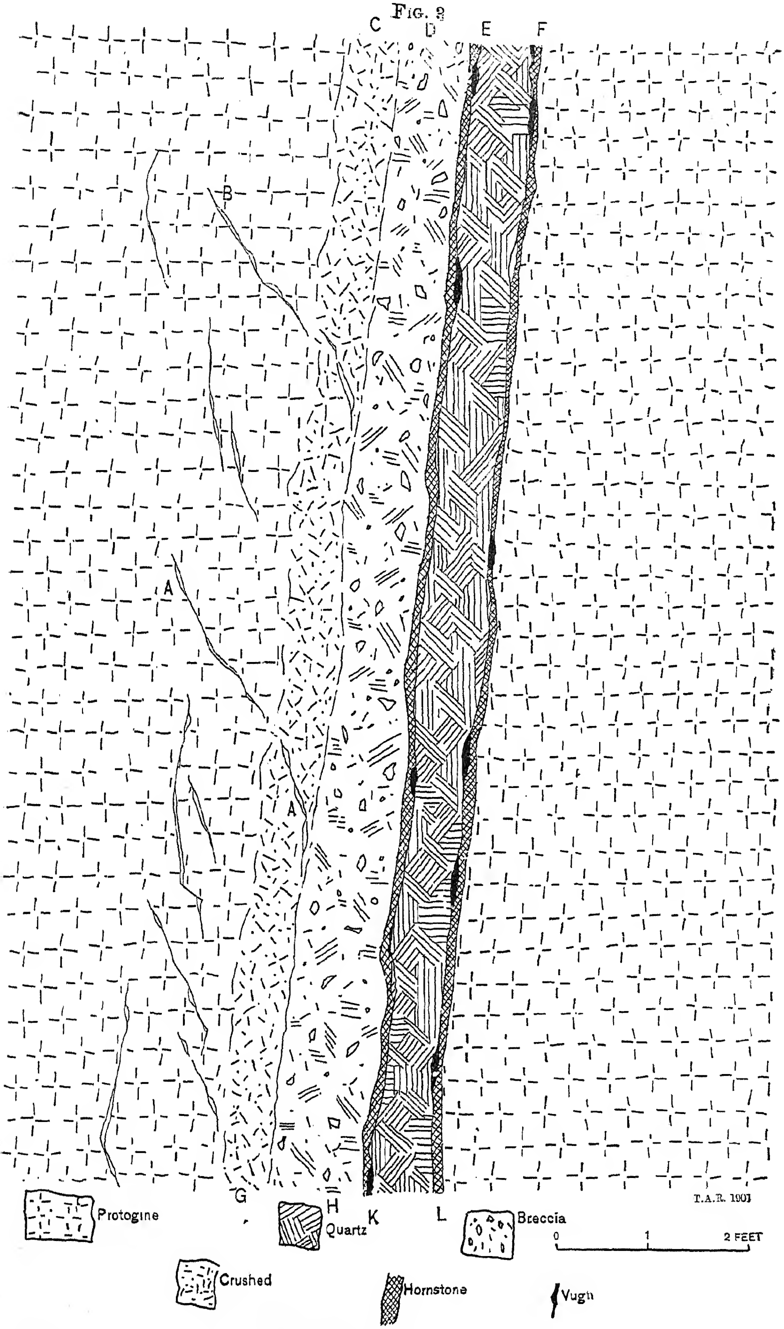
Kalgoorlie shares with Cripple Creek the honor of having brought tellurides to the front rank among the ores from which gold is won. The two districts have been likened, but erroneously. Their geological unlikeness is their most interesting feature.

The veins occur in chloritic schist, the vein-stuff being essentially the same as the encasing country-rock, but more schistose in structure and more calcareous in composition. There has been much discussion among petrographers concerning the original character of the country enclosing the veins.† The alteration in the rock induced by extreme metamorphism has

* See "The Telluride-Ores of Cripple Creek and Kalgoorlie," *Trans.*, vol. xxx., pp. 708–718. Fine specimens of roscoelite have been lately obtained from the Logan mine, near Crisman, in Boulder county. Roscoelite is named after Sir Henry E. Roscoe, the celebrated chemist.

† Most of the evidence on this mooted point is well summarized by Mr. George W. Card, in vol. vi., part i., "Records of the Geological Survey of New South Wales," 1898.

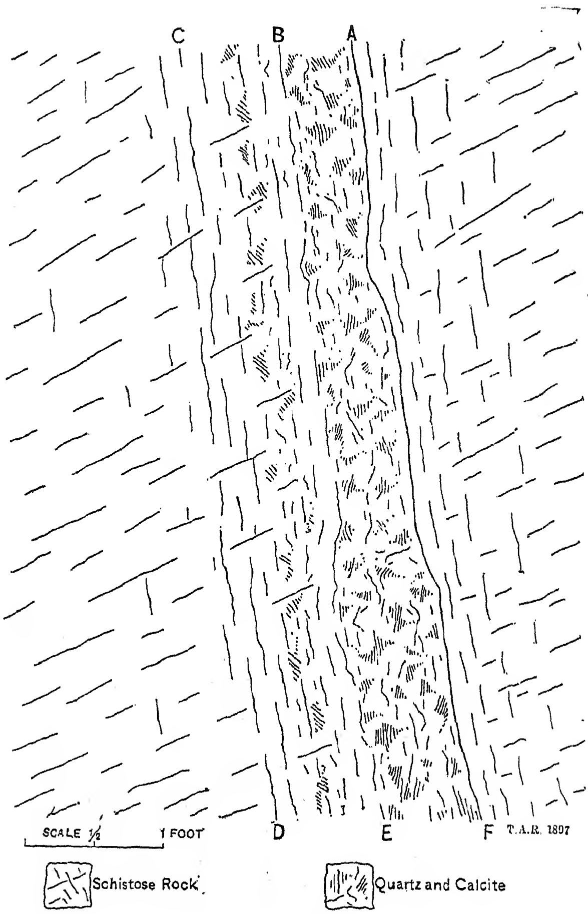
FIG. 3



MONONGAHELA VEIN, NO. 2

rendered the conclusions of observers anything but unanimous. In the district itself the term "diorite" is loosely employed by the mine-managers to describe the prevailing formation, but microscopic sections exhibit a good deal of quartz and no horn-

FIG. 4



A KALGOORLIE LODE

blende, and therefore prove that term to be inappropriate. Some feldspar can be detected. Titaniferous iron and mica are present. From sections which I secured in 1897, Prof. Judd, F.R.S., concluded that the prevailing rock was a highly altered

quartz-andesite. As the formation appears underground it is a fine-grained foliated rock or schist with a silvery-green sheen and a fissile structure. It is rendered tough, and also soft, by reason of the calcite and sericite (or hydrous mica) which it carries.

A typical lode is illustrated in Fig. 4, which shows the face of the 270-ft. level in the Great Boulder Main Reef mine, on Oct. 18, 1897. It is a schistose band of rock with a well-defined line of parting, A F. This "east wall," as it is termed, forms one boundary of the gold-bearing rock, that is, the lode, which has no defined limit on the west, but graduates into the country-rock on that side. There is an evident struggle between two systems of fracture; the rock which is ore-bearing, A C, D F, is sheeted along lines which are nearly upright and parallel to the parting, A F, while the surrounding country has a contrary cleavage. The ore differs further from the surrounding rock in being traversed by veinlets of calcite and granules of quartz arranged along the lines of fracture. Iron pyrites is also liberally scattered through this calcareous vein-stuff. Petzite and calaverite gave the lode here illustrated an average value of 3½ ounces of gold per ton.

The telluride-ores of Kalgoorlie appear sometimes to occur in long, overlapping lenses, as is illustrated in Fig. 5, which represents a series of ore-bodies cut at the third level of the Lake View Consols mine. It is said that the original owners of this now famous property followed the line of one of these long, torpedo-like lenses, and, not knowing the nature of the occurrence, their workings ran out into barren country so as to necessitate a cross-cut, which, unfortunately, was put out on the wrong side, with the final result that they concluded, as a Cornishman would say, "that the lode had just naturally petered out." The ore tends to spread from one plane of foliation in the schist to the next one on the right, with the result that the longer axis of each lens makes a small angle with the strike of the country, and the successive lenses follow one another *en echelon.** An occasional "wall" may be prominent

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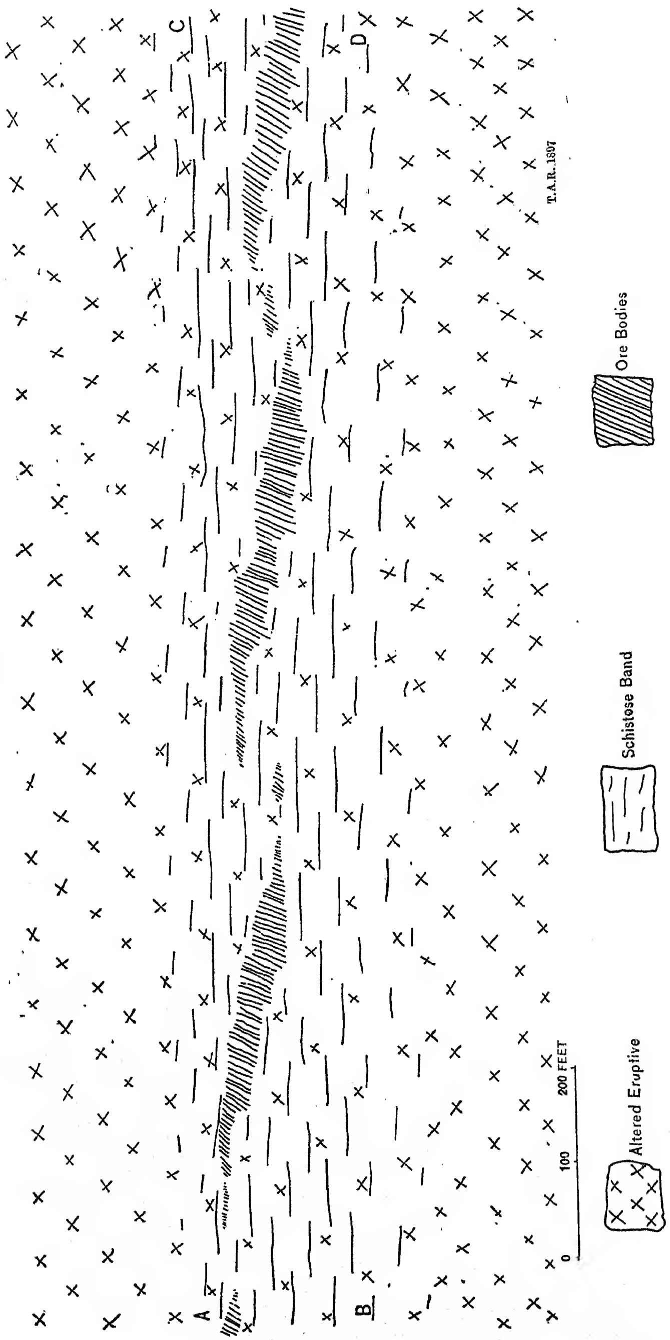
* A military term descriptive of the movement of troops advancing in diagonal step-like succession.

Fig. 5



ORE OCCURRENCE IN THE LAKE VIEW CONSOLS MINE

and the ore may follow it for a short distance, but it will leave it for another, equally well-marked. The "walls" or planes of parting do not limit the ore-channel; some of them are within it, some extend beyond it, to become faint as they are followed into the surrounding country. In the space separating the lenses there are stringers and small seams of ore which serve as connecting threads of discovery. They act as "leaders,"* guiding the observant miner from one ore-body to another.

The description of veins in two districts so far apart on the map as Boulder in Colorado and Kalgoorlie in West Australia emphasizes the diversity of structure characteristic of the lodes which carry gold. Both types of veins occupy fractures which have been healed by mineral solutions; the Boulder type is distinctly a segregation of amorphous quartz in the form of flint, with a cementing of the adjacent granite, which had been brecciated at the time of the formation of the vein-fracture; the Kalgoorlie type represents a sheeting of the schistose country without any clean-cut fissuring and without a brecciation of the country, which, being more tough than a granular rock, such as granite, and less fissile, exhibits the effects of strain in a system of parallel sympathetic partings, along which calcite and quartz have been deposited, and, with them, the tellurides of gold. In the Boulder type the tendency is to produce tabular ore-bodies known as "shoots"; in the Kalgoorlie type the struggle between schistosity and sheeting, along a sheer zone, produces "lenses."

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* This is an Australian term which is worthy of adoption. Leader is from the A. S. lædan, to guide, just as lode is from lād, a path. A lode is the occurrence of ore which guides or leads a miner.

The Lodes of Cripple Creek.

BY T. A. RICKARD, DENVER, COLORADO.

(New Haven Meeting, October, 1902.)

A. INTRODUCTORY.

IN a former paper* the writer has described the essential features of the general geology of the Cripple Creek region. In the present account it is intended to examine into the occurrence of the ores, the value of which has made this district the most important among existing American gold-fields. The production of Cripple Creek from its discovery, in 1891, to the close of 1901, has reached a valuation of fully $125,000,000. During the past year (1901) the output amounted to $17,285,470. In 1900 it was $18,174,681.

The first discoveries, which led to the development of the district, were made in the spring of 1891, but it was not until 1893 that vigorous work was commenced. A great impetus was then given to the exploration for gold on account of the sudden drop in the market-price of silver, caused by the closing of the Indian mints in the summer of that year. This induced an energetic population from the older silver-mining camps of Colorado to go to the new gold-field, which was then beginning to attract attention. Prospecting, at first, was hindered by the comparative absence of outcrops, due to the fact that the surface of the hills is covered with a considerable thickness of shattered rock, resulting from the action of frost at a high altitude; but so much indiscriminate digging was done that a number of rich veins were uncovered, and this stimulated the search for others. The advanced condition of the mining industry of Colorado offered unusual facilities for exploration and reduction; progress was therefore rapid, with the result that the district soon achieved great prominence.

* "The Cripple Creek Volcano," *Trans.*, xxx., 367–403. It is proper that reference should also be made to the more authoritative monograph on the "Geology and Mining Industries of the Cripple Creek District," by Whitman Cross and R. A. F. Penrose, Jr., *U. S. G. S.*, 16*th Ann. Rept.*, Part 2 (1895), pp. 1–209.

B. Geological Character of the District.

The geological environment of the gold-bearing veins can be outlined briefly. The district occupies the ground-floor of a volcano, the superstructure of which has been removed by erosion. This basal wreck of material erupted during the Tertiary period now survives as a complex of volcanic rocks, filling the hollows and occupying the plug of a basin which is surrounded by the granite of Pike's Peak. The volcanic area of Cripple Creek occupies about nine square miles, and consists, for the most part, of breccia, in which andesite predominates. Penetrating the breccia in every direction are numerous dikes, composed of various rocks, those of basalt and phonolite being the most notable, on account of their close association with the occurrence of ore.

The mine-workings have reached a maximum depth of 1400 ft. Added depth appears to have affected the persistence of the ore to the same extent as experience elsewhere would lead one to expect. The veins situated near the edge of the breccia have in several cases been followed downward in their penetration of the underlying granite, and it has been demonstrated that some of the ore-bodies have continued from the upper into the lower geological horizon. The distribution of these ore-bodies offers the same perplexing problems as in other gold-fields. Extensive developments, due to very successful mining, have, however, afforded a great deal of interesting evidence, the consideration of which may contribute toward the better understanding of the economic geology of the district.

The mines exhibit examples of a great diversity of lode-structure. This diversity is mainly traceable to the complexity of the enclosing rocks. The variations in ore-occurrence due to this fact explain the vicissitudes which marked the early history of the district, and the recognition of them should promote the success of future exploratory work.

During the past five years, while examining a dozen of the principal mines, the writer has gathered many examples of vein-structure which are herewith submitted as testimony bearing upon the ever-fascinating problem of ore-occurrence. As a poor witness may sometimes furnish a good lawyer with an illuminating bit of evidence, so the writer hopes that this testimony may be of service to the geological philosophers who are engaged in the study of ore-deposits.


THE INDEPENDENCE VEIN
SCALE 0 1 2 FEET
GRANITE
PHONOLITE
ORE
T.A.R. 1900.
A
B
C
D
E
F
G
K
L

Fig. 1

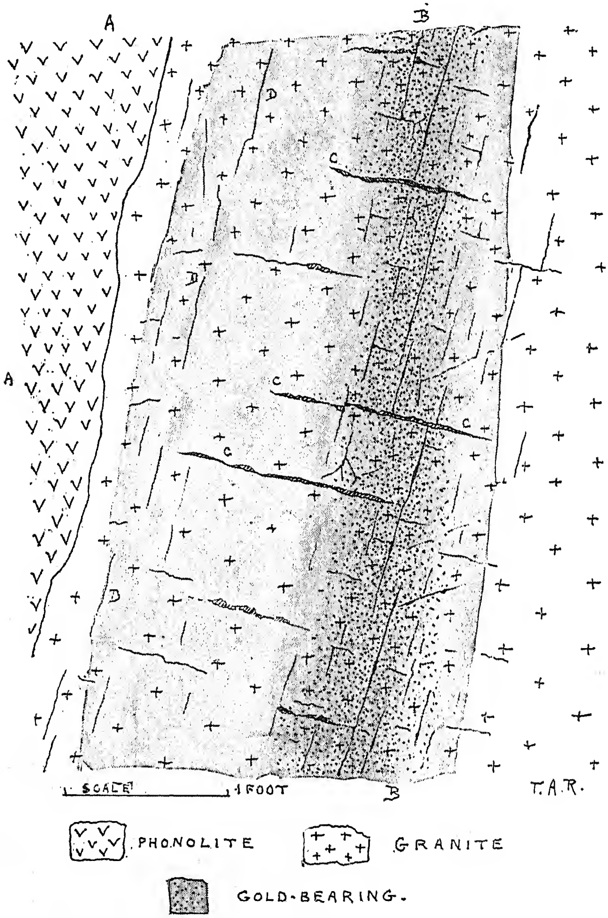
C. A Type of Lode-Structure.

A small section of a single vein will sometimes typify the lode-structure of an entire region. Such I believe to be the case in the occurrence which is illustrated in Fig. 1. It represents the vertical section of a portion of the Independence vein as it appeared just south of the station at the second level from the No. 1 shaft. The scale indicates that the space covered is about 10 ft. high by 16 ft. wide. The country-rock is the pink, coarsely crystalline Pike's Peak granite; the vein, A K, L C, appears as a band of iron-stained, decomposed granite alongside of a phonolite dike, A B, C D, which throws out a nearly horizontal tongue, E F, G H, into the rock on the west. This offshoot from the dike is crossed by the vein, and it affects the distribution of the ore. Thus, while the decomposed gold-bearing granite, constituting the lode, is about 1–1½ ft. wide both above and below this intrusion of phonolite, it is broken up at the place of crossing into a few stringers cutting through the phonolite; so that, while the lode maintains its continuity, it does so with difficulty. An important feature of the section is the evidence obtainable as to the relative age of the phonolite and the joint-planes in the granite. The phonolite is, of course, younger than the granite which it penetrates. But this is not all; it is also apparent that the joints in the granite are more recent than the dike. Observe how the joint-planes, E F and G H, cut through the protruding sinuosities of the outer edge of the phonolite. It remains to add that there is a distinct division, but no selvage, between the hanging-wall, A C, of the vein and the dike which it accompanies, while on the other side, K L, the vein is not marked by any clear line, but graduates, by the lessening of the evidences of decomposition, into the outer granite. The east wall, B D, of the dike exhibits a marked selvage, and it is also accompanied by traces of ore. On the joint-plane, G H, which is nearly horizontal, there is a slight, but evident, selvage.

The story told by this section is that the phonolite penetrated the granite; that, subsequently, a line of fracture was established alongside the phonolite; that this afforded a passage-way for ore-bearing solutions; that the impregnation of ore was less where the solutions passed through the protruding tongue of phonolite, because there, the rock being closer-grained and

more fissile than the granite, it was broken by a very few decided cracks, rather than by an irregular multiple fracturing such as determined the diffused mineralization constituting the lode in the granite; further, it is evident that the jointing of

FIG. 2



the granite, due to a condition of strain, must have occurred subsequent to the intrusion of the phonolite, because the joints cut through the edges of the phonolite;* finally, it is rendered

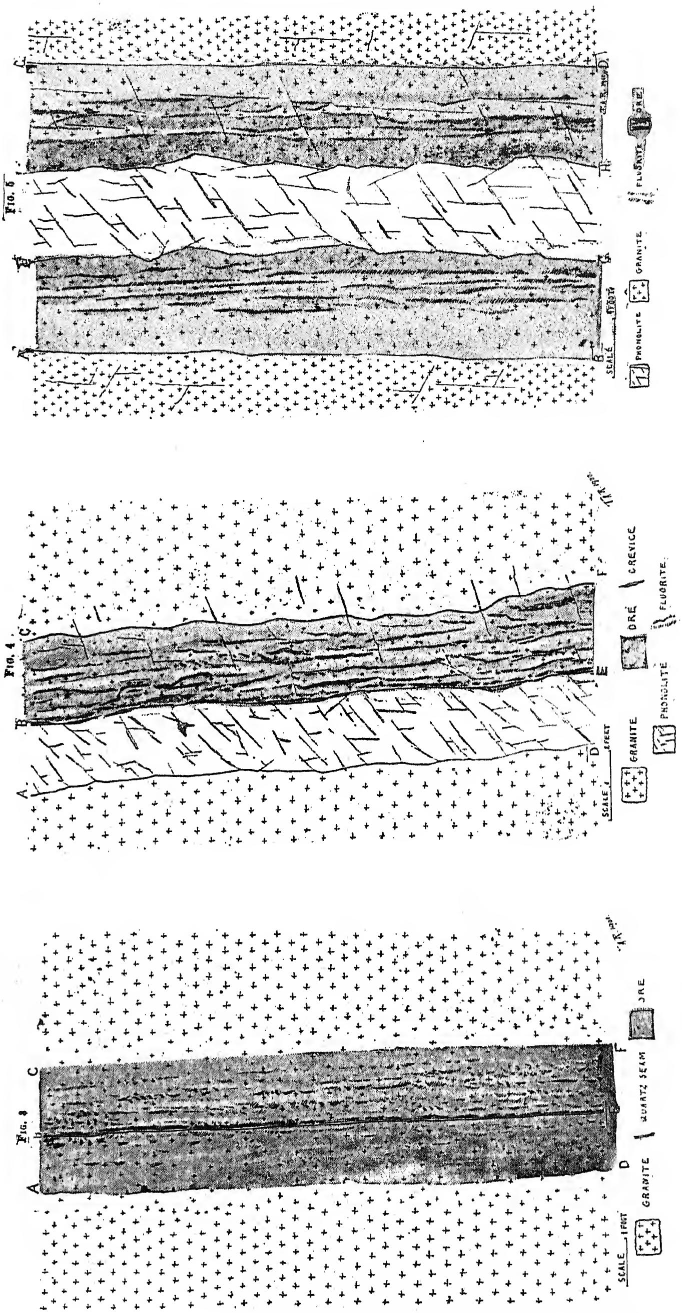
* Of course it is possible that the cracks through the phonolite are merely the prolongation of the joints, and that this extension of the latter may have been of later origin; but this is not my interpretation of the evidence as I have seen it.

very probable that the jointing of the granite and the fracturing now identified with the lode were contemporaneous, both being the result of mechanical stresses connected with the earth-movements which followed the last stages of volcanic activity in the district.

D. General Characteristics of the Veins.

The foregoing example will serve as a text for a preliminary statement. The lodes of Cripple Creek are essentially lines of fracture accompanied by a variable width of rock, the constituents of which have undergone replacement by fluorite, quartz, pyrite and other gangue, together with gold-bearing tellurides. The width and distribution of the ore depends upon the extent and character of the fracturing; the study of the latter is therefore of vital importance to the miner. Owing to the number of volcanic rocks occurring in the district, the veins differ greatly in appearance; but this difference is traceable to diverse structural conditions rather than to diversity of origin. In all the lodes which I have examined, the ore is essentially rock in place, however much altered; the lodes are to be regarded as bands of replacement, rather than the filling of open fissures or crevices; nor is there any departure from the rule that the lodes were formed during a late period in geological history, for the ore is, in every case, as far as I know, subsequent to the intrusion of the eruptives which penetrate the breccia, itself of late Eocene or early Miocene age. While these eruptives cut across each other and thereby evidence their relative succession in geological time, they do not appear to cut across the ore-veins, which, on the contrary, pursue their course amid varying petrographic conditions, unchecked but not unchanging, for to the changes due to this variable rock-environment we owe the extremely interesting variations in ore-occurrence.

The lodes have originated from lines of fracture formed subsequent to all the members of that volcanic complex which constitutes the gold-field. These fractures are the outward manifestation of lines of weakness, or of such comparative weakness as is the equivalent of least resistance; therefore, it is not at all surprising that the veins frequently follow the planes of contact between rocks which are unlike in hardness, and especially the very close-grained eruptives when these traverse the coarse-textured breccia.



THREE STUDIES OF THE INDEPENDENCE VEIN

For this reason phonolite is closely related to the occurrence of ore,—so much so, indeed, as to be often confounded with the origin of that ore. The later dikes of basalt are also notably connected with important lodes. It is possible to generalize further and state that the dikes, especially the very numerous dikes of phonolite, spread outward toward the edges of the volcanic area, and, as a consequence, the strike of the principal veins also has a radiated distribution. The latter are dependent in their strike upon structural relations coincident with the dike system, the arrangement of which points to the approximate position of the volcanic vent, or vents, supposed to be situated somewhere in the central portion of the district.

From these preliminary considerations it is evident that the study of the district, from the point of view of the miner, resolves itself into the endeavor to understand the structural relations of the ore-deposits as affected by the fracturing of the rocks. Questions of origin may be of greater interest, because they appeal to the scientific imagination, but they do not have any direct bearing on the economics of mining. To those who conduct mining operations it is not so much a question of "Where did the gold come from?" as "What are the conditions which determine the distribution of it among the rocks now penetrated by mine-workings?" Therefore, the patient deciphering of complicated systems of fracture will be of more immediate help to the miner than the broad philosophic considerations which render the science of ore-deposits so fascinating to all of those who are interested, even indirectly, in mining.

Before discussing the matter any further it will be well to pass in review more of the evidence afforded by the examination of the lodes as seen underground. For the sake of convenience, it is considered advisable to divide the lodes according to their encasing rock, which is also their matrix.

E. Lodes in Granite.

The granite which surrounds, and partially underlies, the breccia of the volcanic area of Cripple Creek forms a part of the mass of Pike's Peak, the great mountain which overlooks the district from the northeast, and has given its name to the rock. The country near the mines, however, is not the same as

the Pike's Peak granite, orthoclase replacing, to a large extent, the microcline of the typical rock. The Cripple Creek granite may be described as a pink, rather coarsely crystalline rock, the most prominent constituents of which are biotite (black mica) and orthoclase (feldspar), the latter occurring in large, tabular crystals. The color of the rock is due to that of the orthoclase which has been stained red by iron oxide. Fluorite occurs sparingly, but it is interesting on account of its association with the ores of the district. In different portions of the district the granite presents variations, the most important of which is a very fine-grained rock that, in the form of dikes, penetrates the coarser variety, and is evidently of more recent date than the basal rock of the region.*

Fig. 2 illustrates a gold-bearing lode in granite. It represents the heading of the 160-ft. level in the Hallett and Hamburg claims, near Victor, as seen in April, 1897. The ore appears as an ill-defined band, B B, about 1 ft. wide, which is wholly in granite, but at the same time is only 2 ft. distant from a large phonolite dike, A A. The alteration of the granite, which marks the course of the ore, follows a series of short, overlapping seams, parallel to the line of the dike, and also extends into the surrounding rock along the cross-joints, C C. The width of 2 ft. of granite which separates the vein from the dike exhibits partial alteration along the seams, D D, and carries a feeble scattering of ore. The granite under the vein is fresh and unaltered. In the ore-bearing rock the mica is notably absent, the granite is honeycombed by decomposition, and of the two constituent feldspars, oligoclase and orthoclase, the former is kaolinized. Iron pyrite bespatters the gold-bearing portion, and, by its partial oxidation, stains it dark red.

Fig. 3 exhibits the Independence lode in the Washington claim, which is a portion of the Stratton's Independence property. The lode, which farther north traverses the breccia and is closely associated with a phonolite dike, is seen here as a band of decomposed granite subdivided equally by a central thread of quartz. The ore is essentially granite. The portion A C, D F, is 4 ft. wide, and carries a little over 3 ounces

* This is discussed by Whitman Cross on page 23 of the "Geology and Mining Industries of the Cripple Creek District, Colorado."

FIG. 6.

Anaconda Lode as seen in an Open Cut in 1897.

of gold per ton. The width of 4 ft. which carries gold, and is therefore ore, has no parting or wall separating it from the outer rock, which is granite, and is regarded as waste, but is distinguished from the latter in many ways. The outer granite is fresh and unaltered, exhibiting with great clearness its constituent minerals, reddish quartz, black biotite-mica and pink orthoclase-feldspar. The inner gold-bearing rock is much altered by decomposition and replacement; the orthoclase alone appears to have survived the general destruction; the mica has been removed, and, in its stead, chlorite can be seen in green patches; the original crystalline quartz is largely gone, and the presence of purple fluorite suggests that hydrofluoric acid may have been a primary agent in that removal; secondary hydrous quartz fills many of the interstices between the crystalline constituents of the rock;* in iron-stained cavities free gold can be seen by the aid of a pocket-lens, and the gold is observed to have the dark, lusterless appearance which characterizes it when derived from the oxidation of tellurides. The entire width of this gold-bearing decomposed granite is heavily iron-stained by the oxides resulting from the disintegration of the small crystals of iron pyrites, which can still be seen, in an unaltered condition, scattered throughout the same lode, at lower levels. In the center of the band of ore there is a distinct parting, B E, which is separated from a persistent thread of white quartz, only about a quarter of an inch in width, by a slight selvage of red clay. At a distance, the lode appears as a distinct broad band of iron-stained granite, and it is only by closer examination that the boundaries of it are seen to consist, not of "walls" or of any such evident demarkation, but merely of a transition from decomposed into undecomposed granite.

The Independence vein is illustrated again in Fig. 4, which was obtained on the same level as Fig. 3, but 300 ft. farther to the north, where the vein lies against a phonolite dike, A B—

* This description is founded on the examination of hand-specimens by the aid of a pocket-lens. To those who desire to go into the matter further, there is the detailed description of Mr. Lindgren, together with microscopic sections of this very ore (made from specimens which I gave to Mr. Emmons in 1900), to be found in that most important contribution entitled "Metasomatic Processes in Fissure-Veins," by Waldemar Lindgren, *Trans.*, xxx., 578–692, especially page 655.

D E. The thread of quartz, shown at B E in Fig. 3, is to be seen again as a larger, but less regular seam, B E, in Fig. 4. In this case it is characterized by cavities, or "vughs," as the miners call them, which gave evidence,* at the time they were first encountered by the workings, that they had served as water-holes along a line of underground circulation. This may be considered as marking the line of the original fracture which determined the course of the lode. In Fig. 3 it was in the center of the ore; in Fig. 4 it marks the western limit, and separates the ore-bearing granite from the phonolite. The latter is 20 inches wide, and regular. The lode consists, as in the preceding instance, of highly-altered granite, which is richest along the contact with the dike, and shades off eastward (from B E toward C F) along an irregular wavy line, C F, which in no case has any of the characteristics of a "wall" or defined separation between what is gold-bearing ore and what is barren rock.

These characteristics are repeated in other sections which I have sketched underground. The lodes in the granite are frequently remarkable for absence of definition, as was instanced in Fig. 4, this being due to the evenly granular texture of the rock. Within the zone of oxidation the boundaries of a granite lode are made manifest by the red-brown stain, due to the decomposition of iron pyrites; but below the zone of surface-waters it becomes difficult to distinguish country-rock from ore without frequent assays. When the granite has undergone impregnation it is usually porous, by reason of the removal of the microcline and some of the quartz of the original rock. Whatever biotite, hornblende and epidote it contained are absent from the ore, and their decomposition-product, chlorite, is in evidence. Microscopic sections† indicate that secondary valencianite (a form of orthoclase feldspar) and sericite (hydrous mica) have been formed, and that iron pyrites, fluorite and the tellurides have been deposited within the cavities produced by the removal of parts of the granite, and also along the cracks which traverse the rock. Occasional specimens, obtained from the stopes, exhibit these changes on a scale visible

* By containing water and by being lined with slime.

† See Lindgren, *Trans.*, xxx., 656, and *Genesis of Ore-Deposits*, p. 576.

without any lens. Thus I possess a piece of ore characterized by large crystals of pinkish feldspar (or orthoclase) and a little silvery mica (muscovite) held together apparently in a cavernous mass of quartz, through which bright specks of calaverite are scattered. The quartz contains spots of green, earthy chlorite and a very few minute cubes of fluorite. White quartz, as a distinct veinstone, does not characterize these lodes to the extent usually observable in gold-lodes elsewhere, although secondary quartz is everywhere found penetrating the altered veinstone. Pyrite is also a constant companion of the gold-bearing tellurides, and fluorite is readily to be seen save where, near the surface, it has been decomposed. The occurrence of fluorite has suggested many theories, but the fact that it forms an original constituent of the granite of the Pike's Peak region and the prevalence, in the same neighborhood, of such fluorine-bearing minerals as cryolite and topaz,* renders it dangerous to draw inferences connecting it with the ore-forming agencies. There is the appearance of probability about the idea that the secondary fluorite of the lodes was derived by the circulating waters from the granite of a lower horizon, and it may be mentioned that Fouqué showed that hydrofluoric acid in a liquid state has a notable effect on silica and silicates by first decomposing the uncrystallized silicates, or glasses, and then acting similarly on feldspars and other acid silicates, then on quartz, and lastly upon the basic silicates. Whether hydrofluoric vapor acts similarly is an open question. Under such circumstances, quartz might be attacked before feldspar.

F. Veins in Andesite and Andesite Breccia.

The andesite of Cripple Creek is usually an augite-mica-andesite. It is distinguished by having apatite as one of its constituent minerals. Although this andesite forms the principal element of the breccia, the latter is notably irregular in its composition. Phonolite is sometimes locally predominant, and near the edge of the volcanic area the breccia contains a large proportion of fragments of granite. The breccia, since

* Florissant and the Pike's Peak region generally are celebrated for specimens of topaz. W. S. Stratton, the discoverer and former owner of the Independence mine, was prospecting for cryolite, as a source of aluminum, just previous to his first trip to Cripple Creek.

it was laid down as a product of violently explosive volcanic eruption, has become decomposed and cemented. According to Whitman Cross, the decomposition has led to the "total destruction of the dark silicates," such as the augite, hornblende and biotite present in the original fragments, and in the removal, by leaching, of the compounds resulting from this decomposition.* The result has been to change the breccia from dark crumbling material into a bleached compact mass which, in process of time, by reason of pressure and waters containing kaolin, silica and other cementing substances, has become consolidated into a hard, massive rock. In the vicinity of the lodes the effects of siliceous solutions are rendered apparent by the impregnation of quartz to such a degree as to obscure the original fragmentary nature of the rock and make the finer-grained breccia, or tuff, resemble phonolite in texture and appearance. The variations in the andesite and andesite-breccia are responsible for corresponding changes of lode-structure, as will be presently illustrated.

Fig. 6 is a photograph of the Anaconda lode, as seen in an open-cut, in July, 1897. The lode at this place forms a part of an andesite dike traversing the breccia. The dike exhibits a multiplication of fractures parallel to its walls, and along these lines of cleavage there occur seams of quartz and fluorite carrying tellurides.† In the surface-workings, the gold liberated from the tellurides occurred pseudomorphic after sylvanite, distributed in yellow patches amid purple fluorite, affording specimens of great beauty.‡

When, as rarely happens at Cripple Creek, the lode consists of massive ore notably separated from its encasing rock, it will be found that such definition of structure is due to the presence of fluorite and secondary quartz which have so filled up the interstices of the decomposed breccia as quite to obscure its original character. Fig. 7 represents the main lode of the Gold King mine, in Poverty Gulch. At the time the drawing

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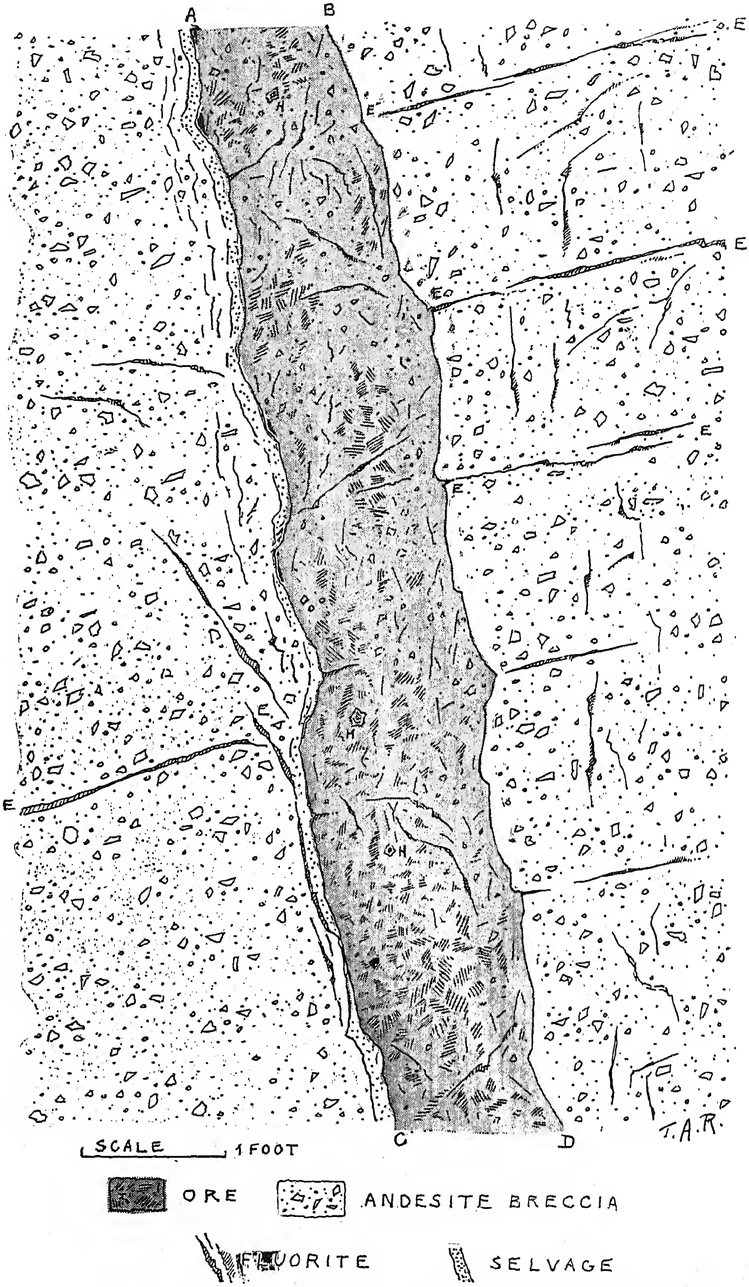
* "Geology and Mining Industries of the Cripple Creek District, Colorado," page 52.

† The general characteristics of the ores of this district have been separately described. "The Telluride Ores of Cripple Creek and Kalgoorlie," by T. A. Rickard, *Trans.*, xxx., 708–718.

‡ See "Further Notes on Cripple Creek Ores," by Richard Pearce, *Proc. Colo. Scientific Society*, vol. v., pp. 11–16.

FIG. 7


A
B
C
D
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E
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E
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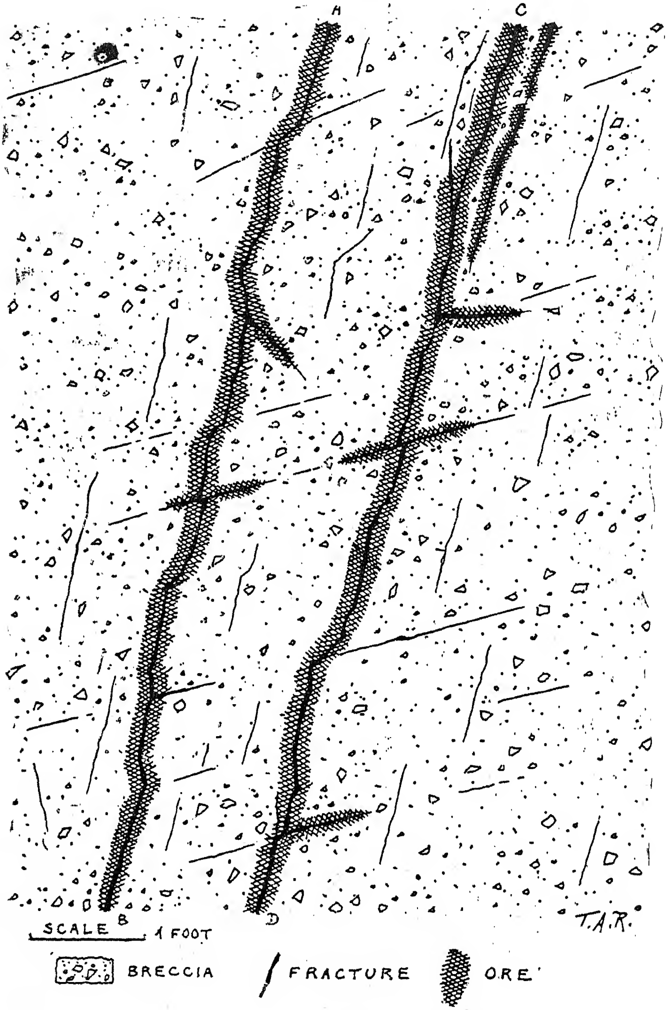
E
H
H
H
T.A.R.
SCALE 1 FOOT
ORE
ANDESITE BRECCIA
FLUORITE
SELVAGE

was made the stopes had a maximum width of 12 to 18 ft. The rock, owing to partial oxidation, seemed, at first glance, to be structureless and homogeneous, but on closer investigation, prompted by contradictory assays, it was found that in the middle of the section afforded by the stopes, which were (fortunately for the purpose of observation) unencumbered with timbering, there was to be seen a compact dark band, A B–C D, from which small seams, E E, went out, almost at right angles, into the surrounding breccia. This band, which was the vein proper, also consisted of breccia, but so impregnated with purple fluorite and so interpenetrated by secondary quartz as to hide the fact. Throughout the massive vein-stuff fine iron pyrites was scattered, and with the pyrite were crystals of calaverite, rendering it very rich. At intervals, small cavities lined with crystalline quartz occurred, as is indicated at H, H, in Fig. 7. In these cavities occurred crystals of native gold pseudomorphic after calaverite. Owing to their dull, rusty exterior, they looked like bits of rotten wood, and it required close observation, especially underground, to detect them. When scratched, they gave instant testimony of their precious nature. Minute stringers of ore, rendered noticeable by the color of the fluorite, followed the cross-fractures or joints in the surrounding breccia, and, as delicate threads, accompanied the central vein, A B–C D, the boundaries of which were further marked by a granular selvage along A C.

Fig. 8 is very characteristic of Cripple Creek veins in breccia. It represents the breast of a level following one of the branches of the Bobtail lode, in the Independence mine, on Battle mountain. The Bobtail lode itself is similar, but its true structure is less evident on account of a more diffused impregnation of ore. The oxidation of the pyrite accompanying gold-bearing tellurides marks the course of the ore-streaks, A B and C D. They look, at a distance, like mere stains; but closer observation discloses the fact that they are partings along the lines of fracture in the breccia, each of which forms the center of a narrow band of oxidized pyrite and very minute, bright specks of calaverite. The latter is seen, under the magnifying glass, to be in process of decomposition, the oxidation of the tellurium of the telluride in the presence of decomposing pyrite having resulted in the formation of the tellurite of

FIG. 8.



IMPREGNATION ALONG PARALLEL FRACTURES

iron* and the liberation of the gold in a brown amorphous condition, resembling yellow paint which has become tarnished.

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* This alteration product has a definite chemical composition, as has been determined by F. C. Knight. See "A Suspected New Mineral from Cripple Creek," *Proceedings of the Colorado Scientific Society*, vol. v., pp. 66–71, October 1, 1894. Mr. Knight's analysis gave a percentage of Fe_2O_3, 32.72; TeO_2, 65.45; and H_2O, 1.83. The physical characteristics ascertained were, a light-brown color, a dull luster, a brilliant and uneven fracture, a hardness between 3 and 4, and a bright yellow streak.

The tributary streaks, along the cross-joints of the breccia, are also gold-bearing for a short distance away from A B and C D.

Such parallel partings as have been shown in Fig. 8 are sometimes so multiplied as to become zones of sheeting. An example is exhibited in Fig. 9, which represents a lode in the Moon-Anchor mine. This type of ore-occurrence is thoroughly characteristic of the mines in that part of the district known as Gold Hill. The breccia is fine-grained. The partings are about a quarter of an inch apart. They are followed by minute seams of red, gritty clay in which the tellurides can be distinguished. The individual seams are united by transverse impregnations which collectively make a pocket or small body of ore, in which it is not unusual to encounter patches consisting of an almost solid aggregate of crystalline calaverite and krennerite.* This sheeted structure dies out into the enclosing country-rock by the process of a gradual widening of the space intervening between each successive parting.

Fig. 10 represents the Emerson vein at the fourth level of the Independence mine. Here, also, the country is andesite-breccia. A central thread, B E, of fluorite and quartz, is followed by a band, A C–D F, about 3 ft. in width, of decomposed rock, which is gold-bearing, and therefore regarded as a lode. This lode appears as a band of bleached rock amid the dark-gray breccia. It is marked by thin veinlets of quartz, and is sparingly honeycombed with small, spongy cavities, containing iron pyrites and fluorite. The ore has no defined boundaries, but in the space from A to C and D to F it averages 2½ oz. of gold per ton.

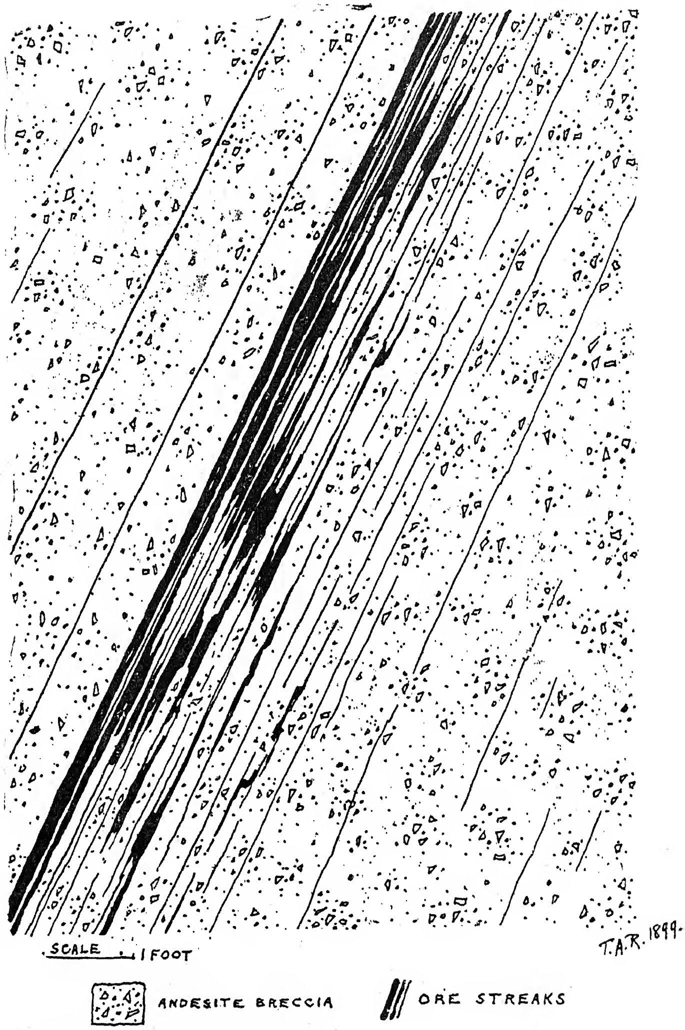
The breccia and tuff exhibit the effects of the thermal waters which have penetrated them during the quiescent stage of the volcano. Kaolinization of the feldspars was the most evident result; the dark silicates also are entirely gone, and are replaced by white mica.† During the subsequent period, when the ore-deposits were in process of formation, these decomposed fragmentary rocks, already partially cemented by their kaolinization, became further consolidated by siliceous solutions, so as

* Krennerite is a telluride of gold, approximating calaverite as regards composition, but differing from the latter in possessing a perfect cleavage. It was named after Professor J. A. Krenner, of Buda-Pesth.

† As observed both by Lindgren and by Cross.

to be changed into a compact hard rock. Underground, near the veins, by reason of the bleaching, due to decomposition, the

FIG. 9.



ORE ALONG SHEETED ZONE

breccia has the mottled look which the miners recognize by the term "porphyry." As in the case of the granite, secondary minerals are readily found wherever the breccia has been

changed into ore and the ground-mass of the rock is seen to have undergone substitution by fluorite and pyrite. The former enters into the ground-mass so thoroughly, sometimes, as to make it a purple rock spotted with bits of bleached andesite. It is a feature of the breccia that the ground-mass of it has undergone mineralization more extensively than the rock-fragments which it contains,—an observation which illustrates the selective action of the circulating waters. As a consequence, even when it is changed into ore, the included pieces of andesite are conspicuous, and are often edged with the ore-forming minerals, such as pyrite, fluorite and the tellurides. However, the most important change which the breccia has undergone, in the vicinity of the lode-fractures, is its silicification by impregnation with quartz. This is not so apparent as would be imagined, because it does not occur in the form of bands of white quartz or dark hornstone, but rather as an ill-defined width following the dominant lines of fracture. For this reason the ore is often harder than the country-rock, and the workings on the lode require less timbering than the cross-cuts.

G. Veins in Phonolite.

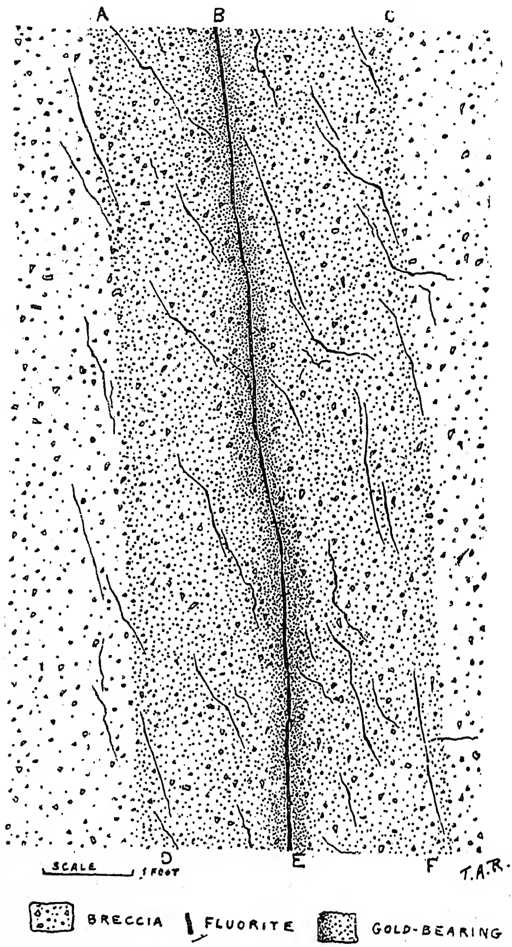
Phonolite is in many respects the most characteristic rock of the gold-field because of the comparative rarity, elsewhere, of this species of eruptive, and its marked association with the occurrence of ore in this particular mining district. The essential constituents of phonolite are nepheline and that glassy variety of feldspar termed sanidine. Sodalite, nosean, and a variety of augite called aegirine, are common to the Cripple Creek phonolite, which, typically, appears as a dull greenish-gray, dense, very hard rock, distinguished from the other eruptives in the district by a schistose structure* that gives it a sherd-like fracture. In the vicinity of the lodes the greenish tint (due to augite and allied minerals) has been obliterated by bleaching, and a speckled or porphyritic appearance is given by white spots of decomposed nosean.†

* Due, according to Whitman Cross, to the fluidal arrangement of the tabular feldspars. *Op. cit.*, p. 33.

† This is especially a characteristic of the so-called Independence dike, as seen at the third and fourth levels of that mine. Professor Judd, F.R.S., from specimens which I sent to him, labelled this rock distinctively a "nosean phonolite." For further discussion of the varieties of phonolite occurring in the region, the reader may refer to Dr. Whitman Cross's interesting descriptions in the "Geology and Mining Industries of the Cripple Creek District, Colorado," pp. 34 to 41.

Phonolite is normally a fine-grained close-textured rock, and for this reason the alteration which it has undergone, wherever it has been in the passage-way of the ore-depositing agencies,

FIG. 10



IMPREGNATION FOLLOWING A SINGLE FRACTURE.

is rendered more striking. The Independence dike, which accompanies a very rich vein, has been so corroded by the solutions as to be a spongy-looking porphyritic rock, especially

wherever it happens to have lain in the path of the ore-bearing solutions which found a way along the vein-fracture. Where not thus altered by impregnation, the phonolite is often so cleaved by cracks parallel to its walls, and to those of the accompanying lode, as to resemble a shale. At such places it is usually mineralized by the occurrence of pyrite and tellurides along the faces of the cracks.

The phonolite occurs not only within the central mass of breccia, but also outside the immediate boundaries of the volcanic area, penetrating the granite in dikes and in large, irregular, intrusive masses, one of which forms Mt. Pisgah, so celebrated in connection with the early history of the Pike's Peak region.*

In the distribution of ore, phonolite plays an important part, as the sequel will show. It has already appeared in Fig. 4, but not in so direct a relation as, for instance, in Figs. 5 and 11, now to be described.

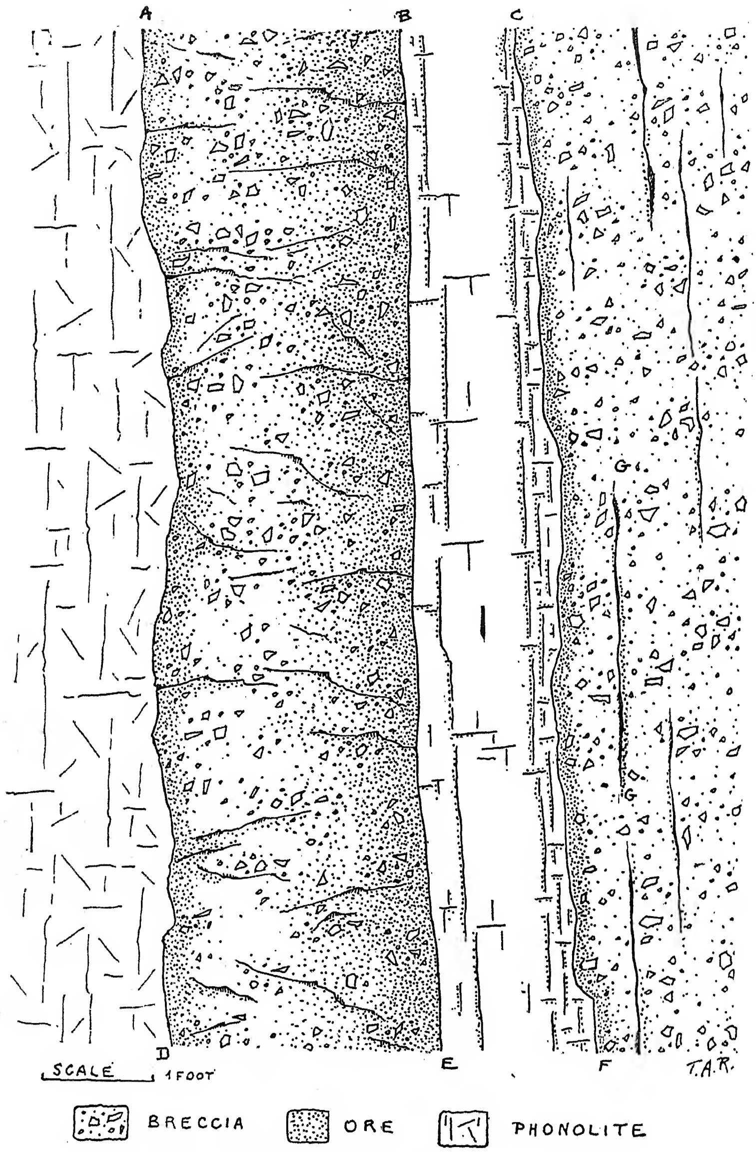
Fig. 11 is especially interesting when taken in connection with Figs. 3, 4 and 5, because it represents the same vein amid a different geological environment. The dike in Fig. 4 is the same as the one, B C–E F, in this drawing, while the body of phonolite to the left is a tongue from a large mass of brecciated phonolite occurring in this part of the mine. The feature to which it is desired to draw attention is the distribution of ore at this point. The dike, B C–E F, is the traversing breccia. The main ore-streak consists of the width of breccia, 26 inches across, separating the phonolite at B E from that at A D. There is some ore also in the phonolite dike, especially along C F, where it is so shattered as to resemble a shale. Threads of ore also occur along the other cleavage-planes in the phonolite, and are (observe G G) widely distributed through the breccia to the east, so as to form a large mass of comparatively low-grade ore. By way of summary, it may be said that the ore is scattered through the breccia and is concentrated near the edge of the phonolite, occurring in the body of the latter only where it happens to be shattered.

In Fig. 5 the Independence vein is again illustrated, as it

* The Mt. Pisgah story is told in my earlier paper, "The Cripple Creek Goldfield," *Proceedings of the Institution of Mining and Metallurgy*, London, vol. viii., pp. 50–51.

appeared in the raise between the 800-ft. and the 700-ft. levels, in June, 1899. The same dike of phonolite, E F–G H, having

FIG. 11



here a width of from 18 to 20 inches, occupies the center of the band of gold-bearing granite, A C–B D, which is the lode.

When sampling the ore, previous to shipment, it was found that the dike only yielded fines or "screenings," indicating that the fine particles, which came off the cleavage-planes, carried whatever gold there was in the phonolite. In the case of the granite, on the contrary, the bulk-ore was the best. The lode extends from A to C; the left-hand portion is about 2 ft. wide, is traversed by streaks of fluorite, and is richest along the contact with the dike. This is also true of the right-hand portion, which is $2\frac{1}{2}$ ft. wide and similar in character. The richest parts follow the dark streaks composed of purple fluorite associated with iron pyrites, accompanied by the tellurides, sylvanite and calaverite.* The walls, A A and B B, are clean and defined, with a slight selvage. The outer rock is a fresh pink granite, the inner lode-granite being kaolinized and otherwise altered.

Fig. 12 was obtained at the fourth level of the Independence mine, at a place where a part of the Bobtail vein, in its northward course, penetrates a mass of phonolite, which, apparently, is only a local enlargement of another dike crossing the breccia at a slight angle with the vein. The main streak of ore, even at this point, is in breccia, so that it is only the enlargement of the Bobtail lode, 5 to 6 ft. wide, which is considered to reach into the phonolite. The planes of fracture are well-marked. Where the ore occurs, the rock is sheeted along lines which are parallel to the lode, and accompanying these fractures there are found small threads of extremely rich material. That marked A A is the largest; it is only from a quarter to half an inch thick, and consists of little crystals of iron pyrites, which, by reason of their partial oxidation, give the ore-streak a dull-red color, and render very distinct its passage through the light-gray rock. Tellurides accompany the pyrite, and are the cause of the high gold-contents of the ore. The other streaks are similar, though smaller. The surrounding phonolite is peppered over with minute cubes of purple fluorite, which darken it. Many of the planes of fracture are lined with the same material. The whole mass, from A A, and across C C, for a width of 6 ft., assayed 3 to 4 ounces of gold per ton.

* And especially a massive granular telluride, found, by Mr. W. E. Ford, to be a variety which, as regards composition, is intermediate between calaverite and sylvanite.

H. Veins in Basalt, Trachytic Phonolite, etc.

Numerous dikes of nepheline basalt, the last product of the Cripple Creek volcano, occur in the district, especially in its southwestern portion. The Raven, Elkton, Anna Lee, Black

Fig. 12.

RICH STREAKS IN PHONOLITE

Diamond, Moose, Bertha, Trail and other mines contain lodes which are an integral portion of such dikes. They are usually much decomposed, by reason of their basic constitution, and do not make any showing at the surface. Of the several lodes associated with these basalt dikes, the Elkton is the most inter-

esting. A characteristic section is given in Fig. 13, which illustrates this lode as seen in the stopes above the fifth level, in May, 1899. The dike is nearly 4 ft. wide, from A C to B D, and traverses the andesitic breccia of Raven Hill. It shows a distinct lamination parallel to the walls. This is very strong along the outer edges of the basalt, where it is also bleached and decomposed. The central portion of the dike appears as a hard, dark-gray mottled rock, marked by evident cross-jointing. The dike is nearly vertical, inclining slightly to the east. The cross-joints dip northward at an angle of about 20°, and facilitate stoping. The basalt exhibits the effects of mechanical stress by its lamination, which is sufficiently pronounced in places to give the rock the character of shale and to render mining dangerous.

Evidences of chemical alteration are apparent, and they coincide with the occurrence of ore. The latter usually follows the west wall, but occasionally it is found on both walls, and more rarely in a scattering through the mass of the dike. The total width of ore in these particular stopes averaged about 18 inches.

A remarkable feature of the section is the inclusion, within the dike, of fragments of granite. The largest of these (at Q) is 4 inches wide. In the neighboring stopes such inclusions were frequently seen. This suggests the vicinity of the basal granite. In fact, the level above which this drawing was made leaves the breccia and enters the outer granite at a point only 850 ft. from the place here illustrated. At an intermediate point, where the Elkton dike is not ore-bearing, I secured the section shown in Fig. 15; here larger fragments of granite are included within the basalt, and the breccia itself is seen to contain numerous fragments of the older rock.

In Fig. 13, which is a characteristic section of the lode, the main streak of ore is seen to follow the western boundary of the dike, and to include the rock on either side of that line, so as to obscure it. There is no parting or selvage to mark the line of division between the basalt and the breccia; that is, it is, as a miner would express it, "a frozen contact." The ore spreads across into both. Both alike exhibit the destruction of their original soluble constituents and the replacement by veinstone, especially fluorite. The breccia is bleached by the

kaolinization of the feldspar, and is honeycombed with cavities which contain water-quartz in various forms, especially hyalite. The tellurides, sylvanite and calaverite, are scattered through this decomposed breccia and extend into the adjoin-

Fig. 14

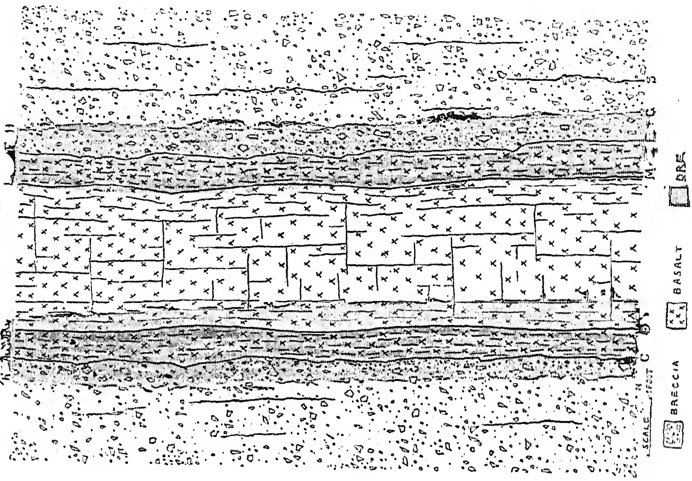
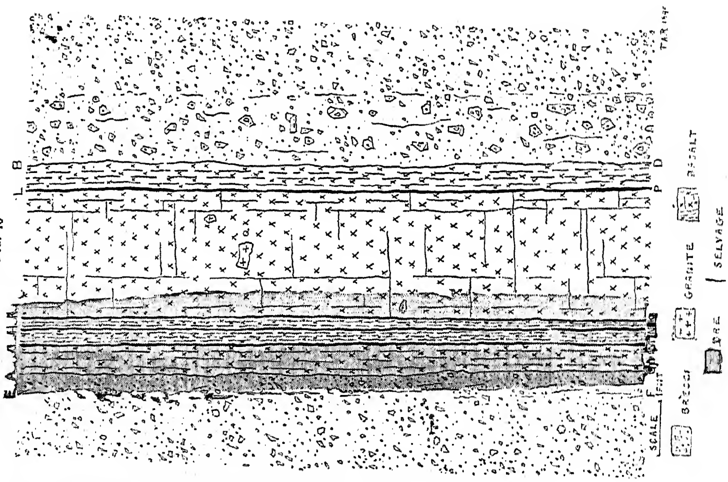


Fig. 15

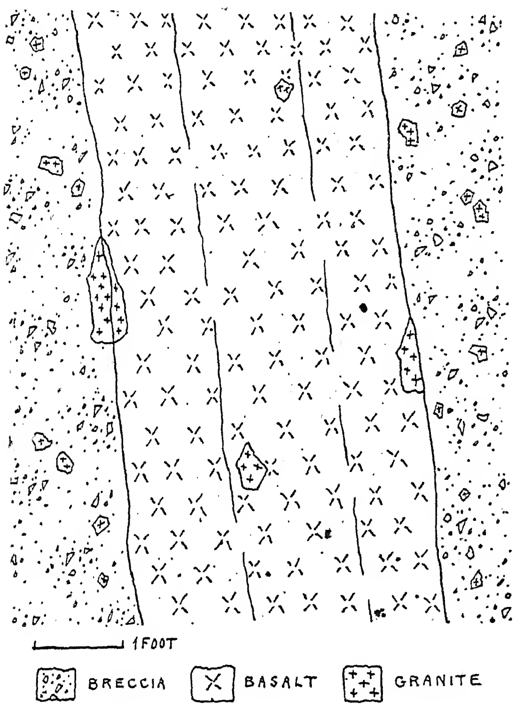


ing basalt. This latter is also bleached to a dull gray, and is seamed with ore along the faces of the cleavages. Although neither the walls of the dike nor the ore-streaks themselves are indicated by selvages, it is noteworthy that several very distinct partings, followed by clay-seams, traverse the basalt in

lines parallel to its strike. They are shown at G M, H N, K O and L P.

This section presents another interesting feature. It will be noticed that on the east side the breccia is brecciated; that is, the fragmentary rock has been broken again into fragments by a later movement which took place along the course of the dike. It is likely that the other side was similarly affected, but

Fig. 15

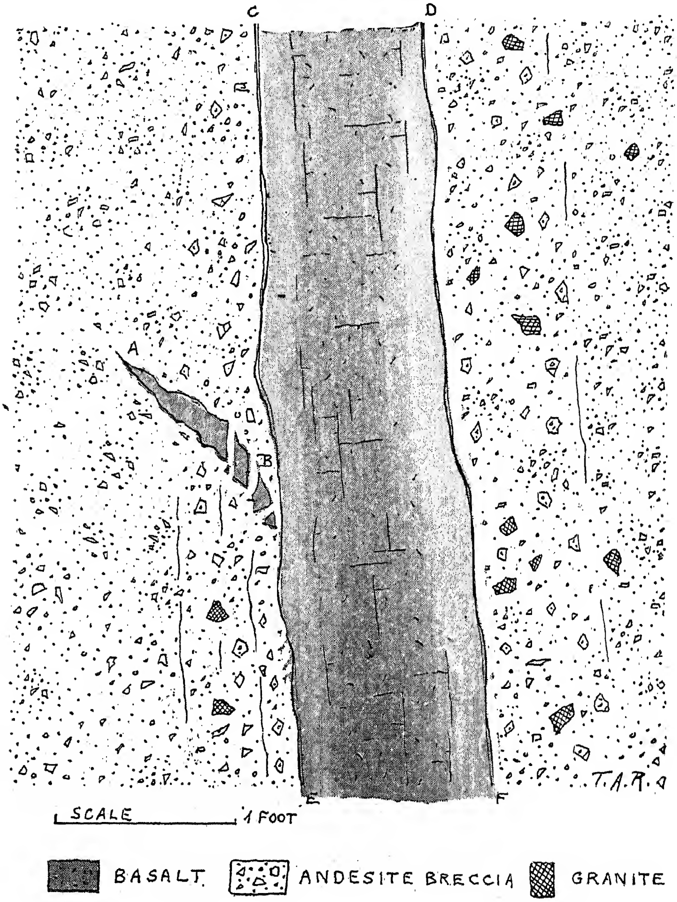


ELKTON DIKE

I could not determine the fact with certainty, owing to the decomposition of the rock and the deposition of ore. That this movement bears some relation to the period of ore-formation is most likely; that it occurred subsequent to the complete consolidation of the dike is rendered certain by another section, shown in Fig. 16, obtained in a neighboring level of the same mine. Here a lateral offshoot, A B, of basalt is seen to

be clearly broken by vertical movement. The central portion of the dike is dark green, with secondary chlorite, and is speckled by feldspar phenocrysts. The dike, C D–E F, only 11 inches wide at this point, also exhibits a banded structure along the sides, suggesting a differentiation between the core and its

FIG. 16



ELKTON DIKE

edges, due to a less complete crystalline development, consequent upon rapid cooling at the time of intrusion into the breccia. The latter is seen to contain numerous fragments of granite, for this section, also, was secured at a distance of 500 feet only from the granite rim.

Another section is illustrated in Fig. 14, obtained in the same stopes as Fig. 13, but about 50 ft. farther north. The dike, A C–F E, is 3 ft. 10 inches wide. It has a very distinctly laminated structure, and in places it breaks like shale. It is spotted with vesicular cavities which are lined with zeolites and hydrous quartz. The ore occurs along each wall of the basalt, spreading over into the encasing breccia. No selvage divides the dike from the outer rock, but the bands of decomposed ore-bearing basalt, A B–C D, and L F–M E, are separated from the central mass of the dike by distinct clay-partings, B D and L M. The ore-bearing edges of the dike are rich in tellurides. That part of the ore-streak which consists of mineralized breccia, F H–E G, appears as a kaolinized rock darkened by spots and streaks of purple fluorite. It is from 2 to 6 inches wide, and is fairly well distinguished from the outer gray breccia by the contrast of color. The enclosing rock is a fairly coarse breccia, marked by sintery spots, due to alteration. These are frequently ore-bearing, by reason of tellurides. The slips or parallel fractures, S S, also carry a little ore upon their faces, and

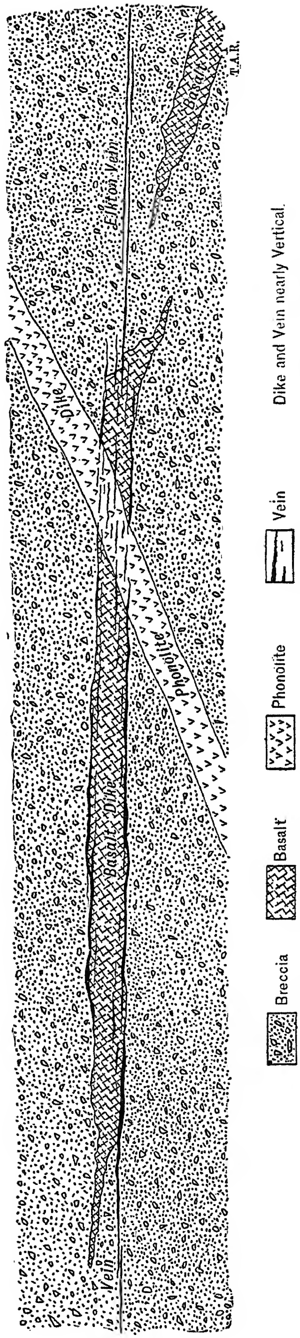


Fig. 17.

COMPOSITE SKETCH SHOWING CHARACTERISTICS OF THE ELKTON VEIN. PLAN

permit the rock to be mined at a profit, because it yields "screenings" or fines, which are rich enough to be sent to the smelter.

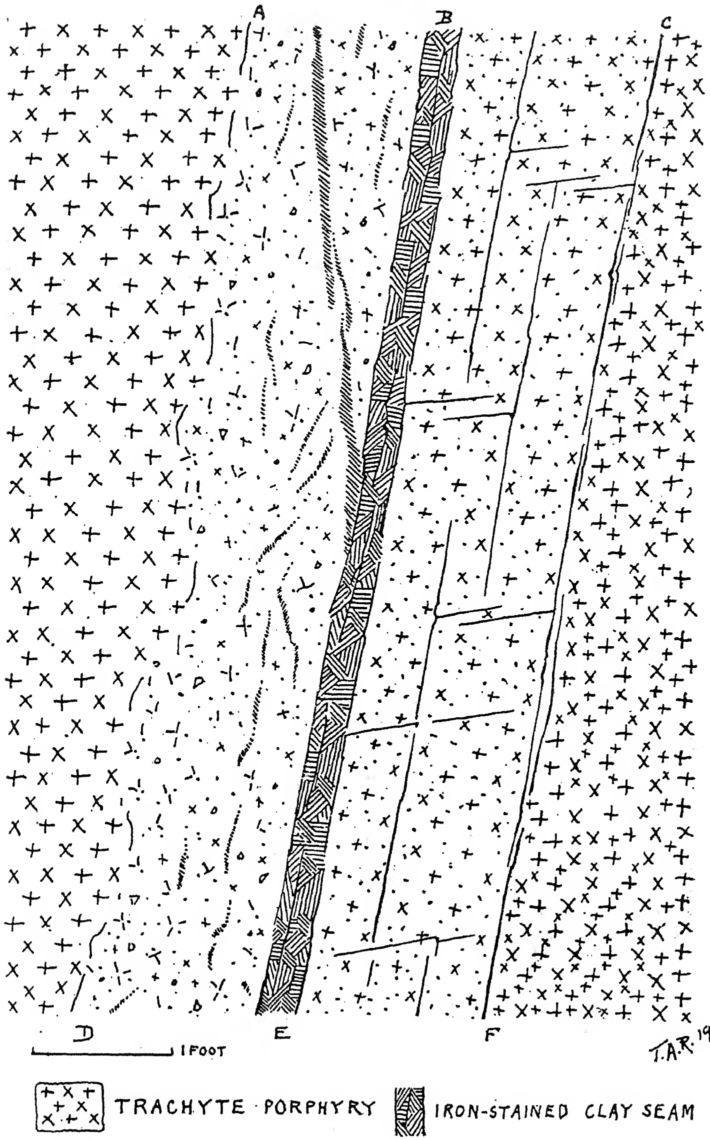
In Fig. 17 there is given a characterization of the chief features of the Elkton lode-structure. The vein is remarkably straight; in the breccia it appears as one or more small fractures carrying tellurides, accompanied by chlorite; when the vein encounters the basalt dike, it follows the latter as long as the basalt maintains a direction similar to the strike of the vein; when the basalt is crossed by a later dike of phonolite, the vein-fractures persist across the phonolite, and spread so as to make a large width of gold-bearing rock.

The trachytic phonolite of Cripple Creek occurs in large intrusive masses, which are penetrated by later dikes of phonolite and basalt. It has a decided porphyritic habit by reason of the occurrence of large orthoclase crystals in a dense groundmass. The workings of the Legal Tender (or Golden Cycle) property are in this rock, and afford examples of lode-structure. In Figs. 18 and 19 the Harrison vein is illustrated as it is seen in this mine.

The Harrison vein consists of a band of shattered country in the trachytic phonolite; the center of it is marked by a leader, usually very rich, bordered by fractured rock having a very variable width. This leader is shown at B E in Fig. 18 and A B in Fig. 19.

In the first example, secured just above the 6th level, B E appeared underground as a streak of crushed rock, 3 to 4 inches wide, and dark-red in color by reason of the oxidation of pyrite. The band of brecciated and bleached rock on the hanging-wall side, from A to B and from E to D, contained numerous little threads and spots of pyrite, accompanied by just sufficient gold tellurides to make it low-grade ore. The corresponding band on the foot-wall, from B to C and from E to F, was less decomposed and exhibited more clearly a defined system of fractures, the latter being lined with fine-grained iron pyrites. In Fig. 19, A B appeared underground as a seam, 1 to $1\frac{1}{2}$ inches wide, of white, gritty mud, very rich in gold. The hanging-wall, from A to C and from B to D, is brecciated and ore-bearing, as is the corresponding band, A E–B F, on the foot-wall; but the latter, being less fractured, is also less rich than the other side of the lode.

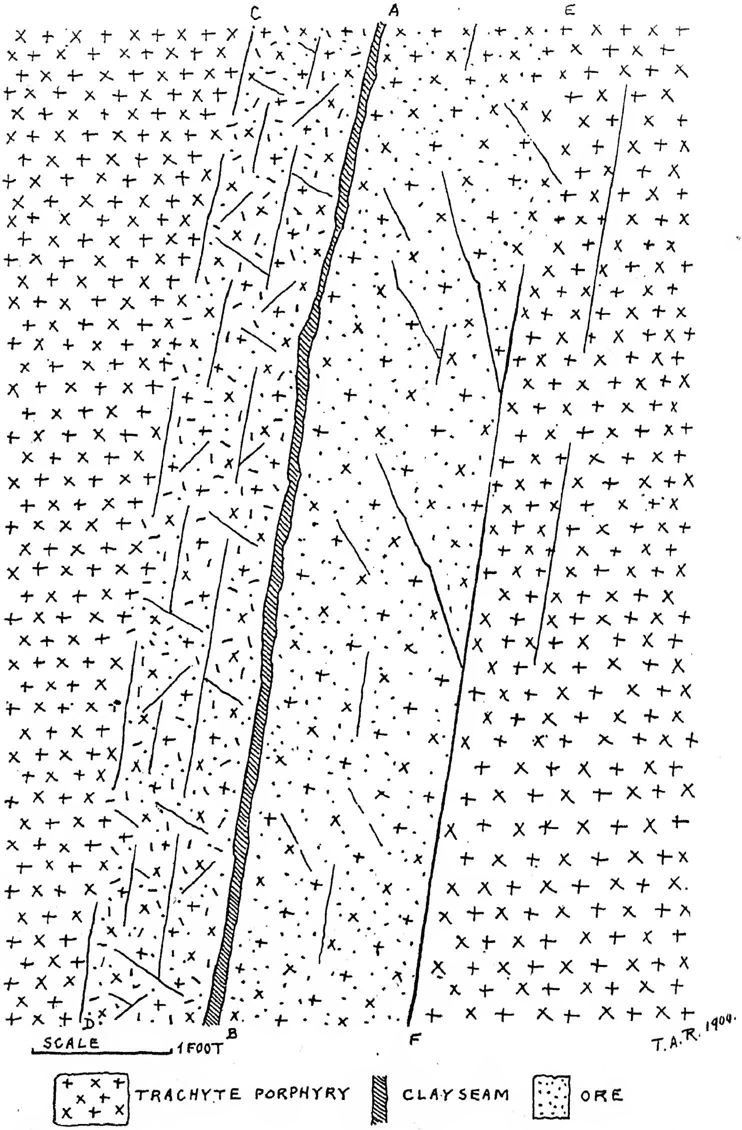
FIG. 18.



HARRISON VEIN

The widest ore found on the Harrison vein is found at places where spurs or subordinate veins joined the main lode.

FIG. 19

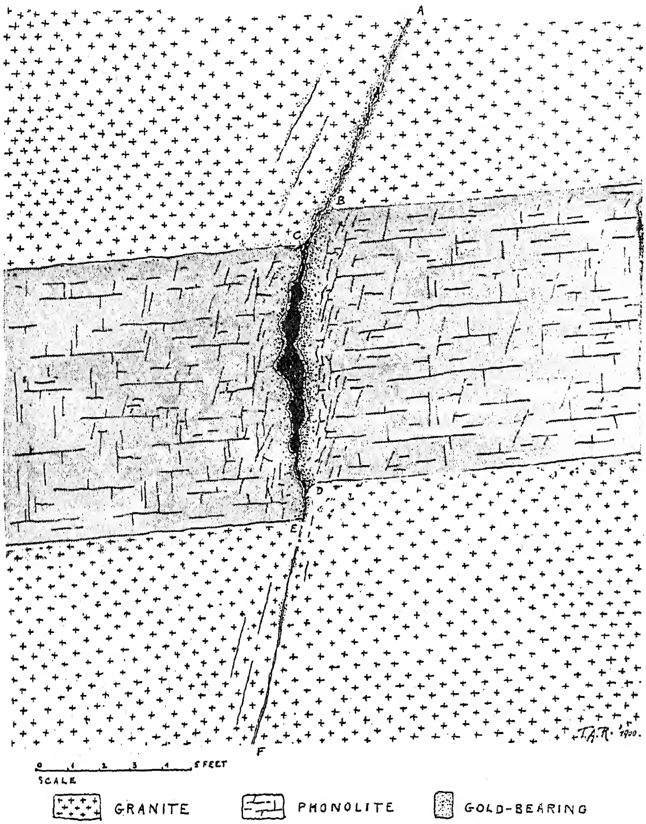


HARRISON VEIN. No. 2.

This gives the ore-bodies a disconnected character, a series of linked enlargements, rather than the appearance of a persistent

ore-streak; when the ore-body narrows, the line of the lode becomes indistinct, being indicated merely by a group of irregular fractures scarcely different from the fractures to be seen in the crosscuts, and not recognized as "veins" simply because they do not carry pay-ore.

FIG. 20



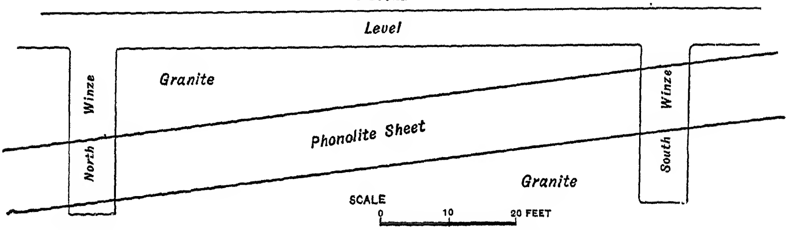
Vein Traversing a Sheet of Phonolite.

I. VEIN CROSSING A SHEET OF PHONOLITE.

The occurrence recorded in Fig. 20 represents the Orizaba vein, on Beacon Hill, as seen in September, 1899. The country is granite, which, in this part of the district, is penetrated by several sheets and intrusive cores of phonolite. The Orizaba vein cuts through at least two of these flat intrusions, and in doing so presents several interesting features. Fig. 21 illustrates the relation between the geological structure and the

mine-workings at 220 ft. below the surface. The phonolite is from 9 to 11 ft. thick, dipping flatly both northward and westward. At the south winze the phonolite is cut at a point $4\frac{1}{2}$ ft. down, and is found to extend thence to a depth of $13\frac{1}{2}$ ft. The remainder of the winze, to the bottom, at $23\frac{3}{4}$ ft., is in granite. The north winze, which is 77 ft. distant from the other, penetrates phonolite at $13\frac{1}{2}$ ft., and strikes granite again at the bottom, 23 ft. down. The phonolite is faulted about 14 in., B to C and D to E, Fig. 20, by the fracture which marks the line, A B D F, of the vein. In the granite the vein appears as a narrow seam, but in its passage through the phonolite it opens out and forms a series of cavities which are lined with long prismatic crystals of sylvanite, encrusted with quartz, affording specimens of great beauty, and, of course, of extraordinary richness. The tellurides also impregnate the rock encasing the fracture.

FIG. 21



This shows the Relation of the Phonolite Sheet (Fig. 20) to the Workings.

In crossing the phonolite, the lode-fracture straightens up; in leaving it, and passing into the granite again, it flattens. While traversing the 9- to 10-ft. sheet of phonolite, and for a farther distance of 15 to 20 ft. into the granite above the phonolite, the vein carries very rich ore, forming a flat body, the pitch of which conforms to the dip of the phonolite. Farther up, the vein becomes impoverished, until, at a point 85 ft. above the 220-ft. level, it encounters another flat sheet of phonolite, characterized by a repetition of the conditions just described. In the stopes above the 220-ft. level the granite is mined not only for the 4 or 5 inches of vein proper, but also for as much as 5 or 6 ft. into the hanging-wall, which is traversed by telluride threads, parallel to the line of the vein. In the phonolite the vein is characterized by "vughs" or cavities, 2 to 8 inches wide, yielding an average of about 5 inches of rich ore. This rich ore does not continue downward into the

granite under the phonolite; the vein thins out, becoming a mere thread amid a series of parallel seams, which give the granite a schistose character for a width of one foot.

J. General Observations.

The occurrence of ore in the Cripple Creek district is intimately related to the distribution of fractures. As a rule, the veins, in their strike and dip, exhibit an evident sympathy with the dikes, more particularly those of phonolite, which are also the most numerous. It is true that the locality of Bull Hill is crowded with a very large number of veins which appear to be independent of dikes, but it is a fact, proved by the experience of mining in the district, that these numerous veins are less persistent and carry ore-bodies which are more uncertain than those, for example, of Battle Mt. and Raven Hill, where the veins are obviously connected with dikes. It is possible to go further and state that the explorations carried out in the extreme eastern and western parts of the region, such as the eastern part of Gold Hill and the corresponding slope of Big Bull, both of which are still well within the volcanic area, have tended to prove that the absence of dikes means the want of a factor usually very favorable to the finding of ore. Nor is this a matter of surprise. The veins are obviously the sequel to the volcanic activity which occurred in this region, and it is a reasonable deduction that the agency of ore-precipitation was linked to that of the thermal waters which marked the last stage of the dying volcano.

The principal veins, such as those which have made rich mines out of the territory controlled by the Independence, Portland, Strong, Gold Coin, Granite, Anaconda, Elkton, Gold King and other companies, either follow dikes or have a course lying closely parallel to them. It is noticeable that the later fracture constituting the vein is apt to be straighter than the older line of fracture occupied by the dike; so that the vein may be compared to a road, alongside a river, which avoids the excessive bends of the latter and keeps a course as straight as is consistent with a given general direction, namely, that of the river. The Independence main lode illustrates this observation, as the accompanying plan will indicate. (See Fig. 22.) This exhibits a portion of the first level where the vein is mostly in the granite. It will be seen that when the vein-

fracture encounters the phonolite dike it follows the latter; or, looking at the occurrence from the opposite standpoint, when the phonolite makes a sharp turn to the west, the vein maintains its general strike. Near No. 1 shaft the vein crosses the

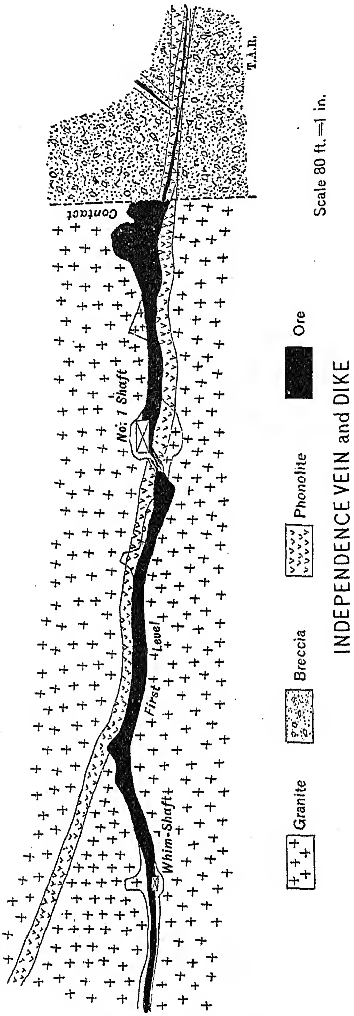


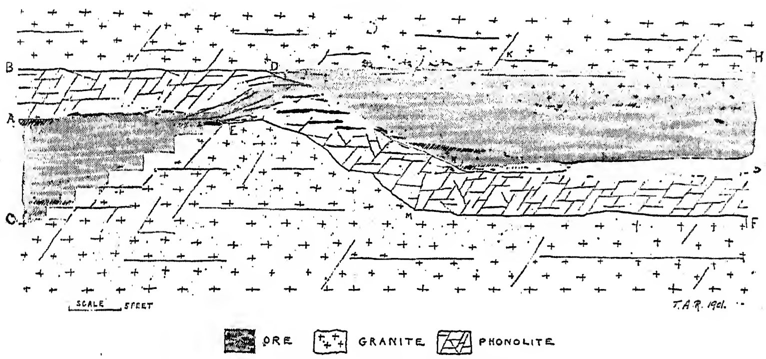
Fig. 22.

dike. This is shown in greater detail in Fig. 23, at E D, where it is evident that the vein-fracture persists in its course despite the fact that it has to cross the sharp bend made by the dike. At the place of crossing, E D, there are one or two small stringers of ore which serve to connect the lode on either side of the pho-

nolite. Between C and E the ore, here 4 ft. wide, narrows down, by steplike succession, from one joint-plane in the granite to the next. Beyond the No. 1 shaft, as will be seen in Fig. 22, the lode widens until, at the contact, it is 10 to 15 ft. across. At this contact, where the overlying breccia rests on the granite, the ore is in decomposed granite, having no marked boundaries save where, on the east, it lies against the dike. Immediately north of the contact the vein narrows and crosses the phonolite only to disappear. At lower levels it has been traced much farther northward.

The obvious connection between phonolite dikes and veins has led to the idea that phonolite itself is notably an ore-

Fig. 23



INDEPENDENCE. CROSSING DIKE.

carrier. This is scarcely true. The details of lode-structure described earlier in this account indicate that the gold-ore obtained from the phonolite comes mainly from the places where the ore-bodies in the granite or in the breccia are in immediate contact with the dikes; or, if ore is found within the phonolite itself, it is at isolated spots, where the line of a lode crosses a dike and makes a scattering along the fractures produced by the crossing. Mistakes in this connection have been made by confounding phonolite with certain finer-grained breccias and tuffs which, by impregnation with quartz, have put on the appearance of a close-textured crystalline rock. This happens frequently in the mines on Gold Hill. Where valuable ore is really taken from phonolite, it will be found that its true character is sufficiently indicated by the fact that it is secured in the form of "screenings." The fine, powdery material obtained by passing the ore over a wire-screen (which separates

all the larger fragments, and concentrates the small proportion of rich ore), occurs as an encrustation, of fluorite and tellurides, which lines the numerous cracks of a phonolite dike. That shattering of the dense, fine-grained siliceous rock appears to be an essential factor in the deposition of the ore. In this connection it is a notable fact that the phonolite dikes are found occasionally to widen into tongues or cores of large dimensions, which, if they lie on the strike of a series of veins, are so much shattered as to permit of a generous dissemination of ore. Such an ore-body, of noteworthy size and richness, occurs in the Independence mine at the second, third and fourth levels, pitching northward more flatly than the contact with which it was originally supposed to coincide, causing a confusion of ideas very detrimental to the development of the mine.

The chief characteristic of the ore-bodies of Cripple Creek is that they are essentially impregnations spreading outward from lines of fracture; therefore, it is not surprising that the distribution of ore is affected by the changes in country. Prof. Penrose has pointed out that "the character of the fissures of the district is much affected by the nature of the rocks they intersect,"* and it is but a further step to connect this observation with the distribution of ore. In discussing this aspect of the inquiry it is preferable to avoid the use of terms such as "fissure," with its old associations of open crevasses and gaping cavities, and to risk the weariness of iteration by employing the word "fracture," which goes no further than to suggest dislocation or breaking without necessarily bringing in the idea of an open space, because the experience of mining in the Cripple Creek district is all against the theory that open spaces are the necessary adjuncts to ore-deposition; and Mr. Becker's well-known dictum, made in connection with the Comstock lode, that "the first condition for a deposit of ore is the formation of an opening,"† is daily contradicted by the underground workings of this district, as it has been by many others with which I am familiar. The open spaces which are frequently encountered, especially in the mines situated on the

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* "Geology and Mining Industries of the Cripple Creek District," p. 143.
† *U. S. Geol. Survey,* Monograph iii., p. 287.

south slope of Bull Hill and on Ironclad Hill, are, as a rule,* notably unfavorable to the finding of ore; and while certain veins, among which the Bobtail, in the Independence mine, may be instanced, are indeed marked by frequent "vughs" or cavities, these cavities do not contain ore, nor is their presence a factor in connection with the distribution of good ore; quite otherwise, all such "pot-holes" are disliked by the mine-foremen, because they coincide with lean places; and by this is understood not only poverty in respect of gold-bearing minerals, but also an absence of gangue, such as quartz, fluorite, and the other constituents of the ores of the region. This all goes to show that the term "fissure" and the associations which go with it are to be avoided in an attempt to convey the real nature of the lode-structure, because it cannot be emphasized too much that the ores of the district occur as a dispersion into the rock where it is traversed by lines of fracture, not only in the fracture itself, which is often only a mere parting, but also along the minor cracks and porosities of the enclosing rock.

The physical and chemical characters of the rock—the first more than the second—are, consequently, a primary factor in determining the shape and extent of the impregnation which constitutes the lode. Close-grained rocks are apt to be more fissile and less porous; coarse-textured rocks are likely to break in a larger, more irregular manner, but they are often more penetrable by solutions. The phonolite and the breccia exhibit extreme divergence in this respect. Granite resembles the breccia because it is coarsely granular, but its jointings are more regular; basalt resembles the phonolite in texture, but, on account of its basic composition, the weak places in it are more readily searched out by corroding waters.

This "structural dependency" (as it may be termed) of the lodes in relation to the rock is manifested not only by the character of the vein-fractures, but also in the manner of their impregnation by ore. Thus, while the bands of ore in granite are often wanting in walls, yet on the whole they are less lack-

* An interesting exception was recently encountered on the seventh level of the Elkton mine, where a cavity, having maximum dimensions of 20 x 20 x 35 ft., was found to contain ore and water. The latter was struck in such quantities as seriously to impede operations; the ore occurred in a mass of brecciated rock, lining the fractures and penetrating the shattered country, especially near the periphery of the mass. It looked like a thermal spring which had become choked before reaching the surface.

ing in definition than the breccia, because structural lines in the granite, such as joint-planes, have served as barriers to indefinite impregnation. On the other hand, the breccia, not being composed of a crystalline granular material, but being built up by fragments which are confusedly mingled together, has no defined system of joints, and the width of the impregnation which constitutes the ore will be determined by purely local conditions of fracture; the lodes may have no walls, and, when they are limited by such boundaries, these are apt to be cracks sympathetic with the main vein-fractures and parallel to them. In the phonolite the limits are set up by the sheeting of that rock; the ore, which is infrequently found in phonolite, occurs then as a lining or powdery encrustation upon the faces of the laminæ, and not, as a rule, within the matrix of the rock itself. As the lamination is parallel to the walls of these dikes, the width of ore also has a shape conforming to them.

Faulting on a large scale is conspicuously absent in the mine-workings; that is to say, there is no evidence of extensive movement since the ore was deposited. Penrose has recorded his opinion that "the fissures represent fault-planes of slight displacement."* The amount of this displacement is not measurable, because, as a matter of fact, the multiplicity of the fracturing and the subsequent precipitation of ore has obscured it most effectually, and it is this character of multiple fracture which pervades the entire structure of the volcanic area. To what extent these fractures are merely shrinkage-cracks and to what extent they represent radical movements due to the readjustment around a volcanic orifice, I cannot say. In so far as the question concerns ore-deposition, one can emphasize the fact that all breaks, from a crack to a *crevasse*, are the outward and visible signs of displacement; for without displacement the fracture is only latent, and a latent fracture has no possibilities for ore-deposition and does not concern the mining geologist. Since the ore was formed conditions of comparative rest must have supervened, for this is a direct inference from the comparative absence of faults. This fact, taken with the known age of the volcano, which broke out so late in geological time as the end of the Eocene or early in the Miocene period, points to the recency of the agencies which made the ore-deposits.

* "Geology and Mining Industries of the Cripple Creek District," *U. S. Geol. Survey*, p. 153.

Biographical Notice of Clarence King.

BY R. W. RAYMOND, NEW YORK CITY.*

(New Haven Meeting, October, 1902.)

CLARENCE KING was born January 6, 1842, at Newport, R. I. His ancestors on both sides were New Englanders, of English blood, and among them not a few distinguished themselves in art, science, politics or commerce. His grandfather, Samuel Vernon King (partner in 1803 in the house of Talbot, Olyphant & King, later known as King & Co.), was a pioneer in the China trade, and four of his sons succeeded him in the business. Three of the four died in the far East; and one of

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* In the preparation of this paper I have been assisted by Messrs. James T. Gardiner and James D Hague, of New York City, and S. F. Emmons, of Washington, D. C., each of whom is better equipped by personal knowledge than I am, to give a comprehensive account of Clarence King's life, work, and character. It was, indeed, my desire that one of these intimate friends of his should write this notice, and that I might be permitted to add my personal tribute, with such recollections and impressions of my own as it might comprise. This plan proving to be impracticable, I suggested, and they accepted, the scheme of a joint authorship. But the work grew under my hands until it came to comprise much for which I alone was fairly responsible, and, in justice to them, I can now only assume that responsibility, thanking them for the cordiality with which they have freely placed at my disposal much material, both unpublished and published. Under the latter head I may mention the articles by Mr. Emmons in the *Eng. and Min. Jour.*, Dec. 28, 1901, and *Am. Jour. of Sci.*, March, 1902; and those of Mr. Hague in the *Overland Monthly*, Nov., 1873, and the N. Y. *Evening Post*, Dec. 28, 1901.

I would express also my thanks to Prof. Wm. H. Brewer, of the Sheffield Scientific School of Yale University, for many facts and reminiscences concerning King's earlier career, of which I have made good use, both by direct quotation and otherwise.

This paper was read by title at the Philadelphia meeting of the Institute, May, 1902; but it was not completed until just before the New Haven meeting, in October, at which it was read in full. In view of this fact, and the other fact that Clarence King was a graduate of the scientific school connected with Yale College (now known as the Sheffield Scientific School of Yale University), it has been deemed proper to withdraw the title of the paper from the Proceedings of the Philadelphia meeting, and make it in name, as in fact, a part of the proceedings of the New Haven meeting.—R. W. R.

these was James, the father of Clarence, who was obliged, in order to take the place of his elder brother, to leave his young wife before the birth of his son. He died in 1848, leaving his property invested in the business; and in 1857 the house of King & Co. was ruined by the loss of one of its steamers, carrying a large amount of specie. The young mother, widowed in her twenty-third year, devoted herself to the education of her only son, pursuing for herself many studies, that she might teach him; and becoming at the outset, as she remained always, his sympathetic and competent intellectual companion. On his part, he began as a "mother's boy"—best of all beginnings!—and as a mother's boy, maintaining still in undiminished fervor and unstained purity the filial reverence and affection of childhood, he ended—best of all endings!

His early years were spent at Newport. At about thirteen he entered the High School at Hartford, Conn. He had already shown the characteristic qualities of physical strength and activity; love of nature and the natural sciences (exercised in hunting, fishing and botanizing during summer vacations in the Green Mountains); an almost equal passion and appreciation for literature and art; great powers of entertaining conversation; singularly quick observation and wonderful memory, and (as the poet Stedman lately said of him) "the gift of friendship"—a gift which Mr. Gardiner, his schoolmate at Hartford, declares to have been as marked in him at fifteen as at fifty. I cannot do better in this connection than quote his friend's summary description of King at that period:

"On Saturday, we usually spent the whole day walking in the country. If any question arose as to any object seen during the day, whether we had particularly noticed it or not, King could always describe it from memory with great minuteness. He seemed to photograph unconsciously everything that passed before his eyes, and to be able to recall the picture at will. He studied enthusiastically the botany, the bird and animal life, and the rocks, of the regions over which we rambled.

"Already at fifteen he wrote beautifully, having been trained in literary judgment and skill by his mother, who possessed in high degree both the faculty of expression and power to inspire enthusiasm. From her he received also, besides his literary and artistic tastes and critical perceptions, an ardent hatred of slavery, and a clear foresight of the impending 'irrepressible conflict' of the Civil War."

In 1859, at the age of seventeen, King entered the Sheffield Scientific School at New Haven. At that time the material

facilities and endowments of this institution (or, for that matter, of any other American technical school) were such as we should now regard as ludicrously inadequate to the demands of modern scientific and industrial training. But the Sheffield school had great teachers, who were able to inspire, as well as instruct, many strong leaders of the next decade. Munificent endowments can accomplish much, no doubt. They can create (as they have created, many times within the last half-century), in magical growth like that of Aladdin's palace, splendid buildings and apparatus, rivalling if not excelling the slowly accumulated educational "plants" of the Old World; but money cannot evoke at a word such men as James D. Dana and others like him—pioneers, prophets, leaders, organizers and creators, as well as patient toilers—always learning, while always teaching, and winning fame because they did not think about it, but simply deserved it. At the time when King entered the Sheffield school I was pursuing my own studies in a similar direction abroad; and I remember well the thrill of patriotic pride with which I heard my instructor in mineralogy—himself a man of world-wide reputation—declare that in that department the best book ever published was the wonderful *Mineralogy* of Dana.

But I must not wander too far—yet this is scarcely wandering; for it was Dana, and his worthy assistant (and afterwards successor), George J. Brush, under whom King, with such classmates as O. C. Marsh, Arnold Hague and Samuel Parsons, as well as many others before and after them, received the impulse and training which have borne fruitful results in American history. For such men as these, not less truly than the soldiers of the Republic, discharging the duty devolved upon them by the most critical and glorious half-century of recorded time, effected the preservation of a nation, the industrial conquest of a continent, and the scientific as well as the commercial leadership of America.

During his college course, King was not only active in scientific field-work, but also (as might have been expected) a leader in athletic sports—captain of a base-ball team and stroke-oar of a racing-crew. In 1862 he was graduated as B.S.,—a degree which his class was the first to receive from Yale college, then just waking to the worthy academic rank, as well as material value, of a scientific course.

During the following winter he studied glaciology under Agassiz, and was an active member of an art-club, which studied with enthusiasm the eloquent dissertations of Ruskin, and the work of the American pre-Raphaelitic school.

In May, 1863, together with his friend Gardiner, whose health had been somewhat impaired by over-study, he started for California, intending to make the journey on horseback from St. Joseph, Mo., then the most western railway-terminus. On this journey his faculty of universal sympathy and consequent power of winning friends was strikingly illustrated. On the cars, his kindly attention to the children of a family of emigrants led to the adoption of himself and Gardiner as members of the party in its trip across the plains. The two young men, mounted upon their own horses, were able, by reason of the slow progress of the wagons, to make numerous detours upon excursions of exploration, though not without danger from hostile Indians. The party followed the "old Fremont route," up the North Platte, and down the Humboldt in Nevada, thus traversing the transcontinental belt which King was afterwards to survey; and in this way he gained, no doubt, that general impression of its varied geological features and mineral resources which led him to select it as a fruitful field of study. After crossing the Nevada deserts, the two friends left the party, to visit the already famous Comstock lode. The very night of their arrival at Virginia City the house in which they lodged took fire, and all their personal property was destroyed. They took the situation with light-hearted courage, and worked as laborers in one of the quartz-mills until they had saved enough money for further traveling-expenses. Then they made their way on foot across the Sierra Nevada and down to Sacramento, where they took steamer for San Francisco.

This adventurous journey, taken in connection with King's subsequent career, reminds me irresistibly of a feature in the life of General William T. Sherman—a man possessed of the same tireless activity, hunger for new knowledge and faculty of perceiving, comprehending, retaining and, at need, effectively utilizing, any facts he had encountered, however casually. When asked, in his old age, how he had dared to cut loose

from his base of supplies and risk his whole army in the bold march from Atlanta to the sea, Sherman replied that he would not have dared it, in the absence of detailed maps and other information, but for the circumstance that many years before, as a young Lieutenant of the Engineer Corps, serving in the South, he had studied every stream, hill and road in that region, and learned, never to forget, the difficulties and resources of the country; so that in undertaking what seemed to others a blind and hazardous venture, he "knew what he was about." We shall see that King's great scientific exploration from the Missouri to the Sierra was rendered practicable, at the particular period of its execution, by reason of the early reconnaissance which he had made in person.

On their way to the Golden Gate, the two friends accidentally made the acquaintance of Prof. William H. Brewer (an assistant in the Geological Survey of California); and both were drawn into the service of that survey, then recently organized under Prof. J. D. Whitney.

From a private letter of Prof. Brewer's, I make the following interesting quotation:

"I first met Clarence King and his intimate friend, James T. Gardiner, on Aug. 30, 1863. I had been making, that summer, a reconnaissance in the Sierra Nevada, beginning in the extreme southern part, at Tejon, and zigzagging six or eight times across the divide, my last crossing having been from the northern end of Lake Tahoe to Forest Hill. My party had been reduced by sickness and other causes until, during the last four crossings, I had with me my packer only. It was my desire to continue the reconnaissance northward as far as Lassen peak; but another man, at least, was needed—especially as the Indians were reported to have broken out from Lassen peak to the Shasta valley. So I had left my animals with my packer at Forest Hill and started for San Francisco to see my chief, Prof. J. D. Whitney, with regard to the necessary assistance, and to interview the Indian agent and the military authorities concerning the reported Indian war.

"On the Sacramento river steamer I noticed two young men conversing together in low tones, and curiously glancing from time to time at me, attracted, no doubt, by my costume and appearance, which indicated that I was engaged in rough mountain- or forest-work of some kind, yet not that of the hunter or the miner. Presently they drew near, and the younger one (King) asked, 'Is your name Brewer?' 'Yes,' I replied. 'Belong to the California Geological Survey?' 'Yes.' 'Well; I had a letter of introduction to you from Prof. Brush; but it was burned up the other day!' He went on to say that he had been for three years at the Yale Scientific School (as it was called when he entered it); and that he and his friend had crossed the plains, the interior basin, and the Sierra, since leaving New Haven. Of course, we began at once an acquaintance which soon became, and always remained, a cordial friendship. Many years after, he wrote

on the fly-leaf of the second edition of his *Mountaineering in the Sierra Nevada* (the most brilliant and fascinating of books on mountain-climbing), these words, which I treasure with affectionate pride: 'To Professor W. H. Brewer, my earliest and kindest Sierra friend, to whose friendly guidance I owe my first and my most charming mountaineering, with the unchanging regard of the Author.'

"I may be permitted to introduce here a reminiscence which is likewise most gratifying to me, as showing the part which I unconsciously took in bringing Clarence King to California, and thus initiating the career which was to make him illustrious.

"Both during our earliest conferences and on several later occasions, King told me that Mount Shasta was the magnet that had drawn him irresistibly to the Pacific coast. This magnificent mountain then possessed a pre-eminence in popular estimation which it no longer possesses. It was believed to be the highest peak in North America. Its altitude had been variously reported at from 14,000 to 18,000 ft. From the first, the members of the California Survey looked forward with eager anticipation to a thorough examination of it. We had two barometers made with scales which would show an altitude of 18,000 ft., and after collecting all available information, I was expecting to ascend Shasta in September, 1862. It was a very malarial year, and nearly all my party came down with fever. Of those who were able to work, some had to be distributed to observe station-barometers, for the subsequent comparison with the summit-readings. The rest, accompanied by Prof. Whitney, who came from San Francisco for the same purpose, proceeded to the western base of Shasta, and made the ascent to the summit Sept. 2, 1862. It was the first time that the altitude of a mountain in the United States, more than 14,000 ft. high, had been accurately measured; and we were naturally proud of the achievement. A few days later I wrote to a very old friend and classmate, Professor George J. Brush, an enthusiastic account of our adventure, emphasizing not only the scientific interest, but also the sublime and majestic scenery connected with it. To Clarence King, who happened to call upon him soon after the receipt, Prof. Brush read this letter; and, as King told me many times, 'that settled it.' He resolved to see California, and, in particular, Mount Shasta.

"To return to my narrative: I liked King from the first; he gave me much comparatively recent information concerning my old friends at Yale; I told him my plans; and we arranged to meet in San Francisco. And, at my invitation, he called several times at the office of the Survey in that city, deepening on each occasion my growing affection and esteem for him. I was intensely anxious to get into the Lassen peak region. The year before, I had passed it, going up and down the great valley west of it, and had traced the Cretaceous formation, finding it, at one point, overlain with lava. I now wished to get into some of the cañons which cut through both the lava and auriferous series. All this could be done with safety; but the Indian agent said it would be madness to try to go through, north of Lassen peak, to Shasta valley. I decided to start anyhow, and go as far as I could. King wanted to go with me, as a volunteer without pay. The possible danger of the trip was an additional temptation to him. And Prof. Whitney (who was likewise captivated by his light and ardent nature) authorized me to engage him.

"Clarence King was then in his 22d year, but looked much younger. Of course, he was not so thoroughly informed or so deeply interested in geological problems as he afterwards became. In fact, he stood on the threshhold of that fascinating study, saturated chiefly with Ruskin and Tyndall. The remarks of the latter on the glaciers of the Alps were constantly upon his lips.

"The trip was notable in many respects, and suggested many topics of inquiry which afterwards bore fruit in King's receptive, retentive and intensely active mind. Lassen peak was reported to have been, only a few years before, an active volcano, and offered an opportunity for the study of recent eruptive rocks. The possible glaciers upon Shasta were discussed, as was also the age of the gold-bearing rock-zone of the Sierra, and the desirability of a geological section across the range. Incidentally, the larger scheme of a transcontinental section was mentioned. This had been the dream of Whitney in 1862, when the construction of the Pacific railways was actively begun. He thought that when once a section across California had been completed the railroad companies might be inclined to pay for making one along their lines, across the interior basin and the Rocky mountains, to the great plains.

"We ascended Lassen peak twice, on the 26th and 29th of September, 1863. The first time the day was unpropitious for good barometric work. There was a fierce wind on the summit; a storm was approaching, and the barometer was falling rapidly; and the whole Pitt river valley was filled with clouds, hiding everything below the altitude of 8000 or 9000 ft. But all was clear above, and Shasta, 80 miles away, with the tops of the adjacent mountains only, rose from the white mountain of cloud, projected against an intensely blue sky. King's exclamation was, 'What would Ruskin have said, if he had seen *this!*'

"On the way back he wanted to try a *glissade* down one of the snow-slopes. I objected strongly, being uncertain whether it would be practicable for him to stop before reaching the rocks at the bottom. But he had read Tyndall; and what was a mountain climb without a *glissade?* So he had his way, and came out of the adventure with only a few unimportant bruises.

"Three days later, after the end of an uncomfortable storm of rain, snow and sleet, we made a second ascent of the peak, going up in the night, by bright moonlight, and arriving before sunrise at the summit, where we spent ten hours. The sky was cloudless, and the atmosphere transparent in the highest degree. For a short time after sunrise we could see Mt. Hamilton in the south—normally below the horizon, but 'looming up' long enough and plainly enough for satisfactory identification. This is the longest distance at which, so far as I know, I have ever seen a terrestrial object. Another spectacle of unique perfection and grandeur observed on that occasion was the shadow of the peak projected on the western sky. Although I have often reached greater altitudes, that day stands out in my memory as one of the most impressive of my life.

"It will easily be imagined with what satisfaction and delight these experiences were shared with such a companion as Clarence King, to whose glowing enthusiasm they were new as well as grand. Again, he was fascinated by Shasta. Three days before, the snow upon it had been in patches and streaks; now the snow had covered with unbroken white—save here and there a protruding rock—the upper 4000 or 5000 feet of the mountain. The lower limit of this cap was a sharply-defined 'snow-line.' The great white cone standing upon the dark base, against a background of intense blue, was a memorable picture, and deserved King's rhapsodies of admiration.

"It was in the earlier part of this expedition that the first discovery of the Jurassic and Triassic fossils in place in the auriferous zone of California was made in the Genesee valley, Plumas county. (See *Am. Jour. Sci.*, 2d ser., vol. xli., p. 353; also, *Geol. Survey of Cal.*, "Geology," vol. i., pp. 308, 482.)

"The next year, King and I passed around the eastern base of Shasta. The reconnaissance of this mountain had been made by the California Survey in 1862,

after a winter noted for the heaviest rains and snows since the acquisition of California. And we had then announced that, while there was much snow on the mountain, there were no glaciers. King had never seen glaciers; I had seen them only in Switzerland.

"We forded one day at the base of Shasta a small stream, turbid with ash-colored mud, which came from a snow-field far above. I said that, if we were in Switzerland, I should consider it a typical, glacier-fed stream. 'Why is it not?' insisted King. I told him I had been, only a year before, on the upper part of that very snow-field, and that it showed neither ice nor *crevasses*. I thought the turbidity of the water was due to volcanic dust.

"Six years later, in 1870, King discovered actual glaciers on Shasta, and in 1871 described them in the *Atlantic Monthly* and in the *American Journal of Science*. Two years later, or ten years after our fording the turbid stream, he said to me, 'That stream haunted me for years, until I got on Mt. Shasta and found the glaciers!'

"That was an illustration of the way in which his retentive as well as perceptive mind stored up, and ultimately used, the facts and suggestions it had once received. Another occurs to me. On our trip, in 1863, I talked much about the value of large photographs in geological surveys. I had taken a fancy to stereoptical views especially; and I thought the broken country about Lassen peak should be photographed, and could not be shown satisfactorily by drawings. In later years King was the first to carry out these ideas on a grand scale; and now the camera is an indispensable part of the apparatus of field-work in such surveys. Many similar instances might be given in which King did the things of which others had dreamed."

The foregoing reminiscences of his friend and, at that time, his immediate chief, abundantly indicate the qualities of ambition, energy and endurance which soon won for the young athlete of Yale recognized leadership in the field. The story of his ascent of Mt. Whitney (14,898 ft. above tide), the highest peak in the United States, outside of Alaska, affords an interesting and, in some respects, amusing illustration.

The whole somewhat complicated story is told in an article by Mr. Hague in the *Overland Monthly* for Nov., 1873, from which it appears:

That the name of Mt. Whitney was given in 1864 to the highest of a noble cluster of peaks at the head-waters of the Kern and King rivers by a party of the California Geological Survey, under the direction of Prof. Brewer, and including Clarence King, which was at work in that region during the summer of that year, and some of whom (including King, of course—when was he ever left out, if an adventure was on the programme?) ascended a peak which they called Mt. Tyndall, and from which they saw two others, still higher, to the loftier of which they gave the name of Whitney, their distinguished

chief; that later in the same year, after the party had been withdrawn, King made an unsuccessful attempt to reach this topmost summit; that in 1871 (when no longer connected with the California Survey) he returned, with characteristic pertinacity, to this endeavor, and climbed to what he supposed to be the top of Mt. Whitney, but was prevented from identifying his position by "dense, impenetrable clouds;"* that in July, 1873, Mr. W. A. Goodyear, formerly of the California Survey, with a companion, ascended the summit last named, and clearly saw another and higher one, which was the true Mt. Whitney, already located by observations from other mountain stations, and located upon official maps. This truly highest summit has since been reached by many parties.

Whoever cares to unravel the intricacies of this narrative will find in Mr. Hague's article, already cited, an efficient guide. To me, I must confess, the only important and interesting item in the series is the circumstance that in 1873, as soon as he had heard of the observations of Mr. Goodyear, Clarence King, though no longer connected with any public work requiring from him further attention to the matter, left New York, and, at his own expense, traveled without a moment's delay to the locality concerned, and ascended the true Mt. Whitney, simply to settle, for his own satisfaction, the question which (to use the felicitous phrase quoted above by Prof. Brewer) would otherwise have "haunted him."

Another incident of his work in California deserves mention —namely, his discovery in January, 1864, on the Mariposa estate, of fossils determining the Jurassic age of the gold-bearing slates of California. There was at the time a controversy over the question of "priority" in this settlement of a scientific question. Prof. W. P. Blake had undoubtedly found paleontological evidence tending to the same conclusion. After a laborious study of the contemporaneous documents, I am led to believe that the discovery *in place*, in 1863, of Jurassic and Triassic fossils in the Genesee valley, in Plumas county (mentioned on p. 625), was the earliest well-authenticated and decisive one, and that the credit of this discovery belongs to Prof. Brewer, though it was, in Whitney's subsequent official reports, attributed to him and his assistant King jointly. But

* This ascent is described in King's book, *Mountaineering in the Sierra Nevada*.

it was not regarded as decisive by Whitney, because it did not include the observation of actual gold-bearing veins in the same rock. The Mariposa discoveries made by Blake and King in the country-rock of known gold-mines were conclusive. The question of priority as to these discoveries, involving, as it does, the date not only of the discovery, but also of the first public announcement and the first publication thereof, is really trivial; at least, it will not be discussed here. The record of science is not that of a patent law-suit, in which mere priority governs important rights of property; and neither Blake nor King needed to rest his claims to scientific recognition upon a controversy so unimportant.

His connection with the California survey lasted until the end of 1866; but during that period he was twice loaned, so to speak, for other service—once to the Mariposa Mining Company and once to the United States. The latter episode occurred in the winter of 1865–66, when he acted as scientific assistant of General McDowell in a reconnaissance of the desert regions of Southern California and part of Arizona. His friend Gardiner was detailed to the same expedition. That it was not free from danger, no one acquainted with the condition of Arizona and the temper of the Apache tribes at that time need be told, and others may learn from the following anecdote, which I heard from Mr. King himself, and which Mr. Gardiner confirms:

One day, on the road to Prescott, Ariz., the two friends, absorbed in their work, had ridden ahead, beyond sight of their cavalry escort, when suddenly a couple of Apaches sprang from the bushes, under the very noses of their horses, with arrows aimed at their breasts, drawn to the head, and each held from fatal flight by a single hand. Gardiner's first impulse was to draw his revolver; but King restrained him, divining instantly that the two visible assailants were not alone, and that resistance would be useless. Sure enough, at a signal given, some fifty Apaches emerged from the chapparal and surrounded them. They were ordered by signs to dismount and disrobe. Intent on saving precious time, during which the cavalry might come to their rescue, King distracted the atten-

tion of the savages for several minutes by exhibiting to them his cistern-barometer, and explaining, in Spanish and by signs, that it was a new-fangled gun of very long range. The delay thus gained, however, did not prevent their captors from preparing thongs for their captives, and lighting a fire to be placed upon their breasts, Apache fashion, after they should have been laid, naked and bound, upon the earth. Indeed, they were already half-stripped when the cavalry became visible, and, perceiving the situation at a glance, charged the Indians with such vigor and speed as to capture two of them and scatter the rest. (The two thus taken were released, because the troops were not strong enough to fight the whole Wallapai tribe, as they would have had to do if they had attempted to hold their prisoners.) There is no doubt that King's presence of mind, coolness and ingenuity saved the lives of his friend and himself.

However keenly he enjoyed such explorations of new regions, he realized, as an employee of the California Survey, the importance, as a matter of policy, if no more, of preserving the popular approval and securing the most immediately useful fruits of that great work, by giving greater special attention and prompter publication to the economic features of it. In 1866 he secured the promise of this change, and also (through his personal acquaintance and persuasive personality) assisted largely, if not decisively, in obtaining the necessary legislative support. At one time, I think, he expected to be put in charge of this department, or, at least, of some important division thereof. But circumstances led him to resign from the California survey, and to attempt a larger undertaking on his own account.

Concerning the reflections and considerations which preceded this step, Mr. Gardiner contributes the following interesting reminiscence:

"In the summer of 1866 King and I were working together on a survey of the region east of the Yosemite Valley. I had previously developed and tested methods of topographical work, based on triangulation from peak to peak without signals, and gradually expanding the scale of the triangles, until I believed that the system could be applied to very large areas in a country where peaks were sharp, so that the closure of the triangles could be made very accurate, compared

with what had been done in reconnaissance-work. During that summer we discussed the possibility of carrying across the whole Rocky Mountain system a survey based on rapid triangulation without signals, checked with astronomical work, and with topographical work following the methods which were used in the Yosemite Valley survey and field-work of 1866. We believed that by the application of these improved methods in topography a geological survey was possible which would be far in advance of anything done in the geological survey of California, or any other geological work previously done in the western mountain-system.

"Sitting on the high peaks of the Sierra, overlooking the deserts and ranges of Nevada to the eastward, we worked out the general outlines of the 40th-parallel survey-work. It was the natural outgrowth of our journey across the plains, our experience on the California survey, and our exploration of Arizona, coupled with King's great aggressive energy and consciousness of power to persuade men to do the thing that he thought ought to be done.

"Our study of the structure of the continent in our journey of 1863 across the plains, and in our Arizona trip of 1865, led us to feel that the survey of California and the problems to be solved there were but a part, and possibly a minor part, of the great problems of the structure, topographical and geological, of the whole mountain-system of western America from the plains to the Pacific, and it was from this point of view that the great continental cross-section on the 40th parallel was planned. If King had taken charge of the department of economic geology in the California survey, the execution of this wider plan might have been delayed; but the plan itself was conceived without reference to our temporary California work."

The new scheme was nothing less than a transcontinental topographical and geological survey, for which, with sublime audacity, King undertook to obtain, from the Executive and from Congress, the authority and the means.

Yet the idea was not so chimerical as might have been supposed, and King's intuition of its practicability was truer than any judgment founded upon tradition or *a priori* reasoning. He had already reconnoitered on horseback a large part of the proposed zone of territory; and he had acquired in Arizona and California a field-experience equipping him for all the difficulties of the enterprise. More important still, he had evolved from personal observations and experience the one argument which, backed by his magnetic personality, could, and did, command the support of patriotic legislators.

The building of the first transcontinental railroads had been liberally encouraged as a measure of military and political necessity, for the consolidation of the Union, and the final termination of the minor Indian wars. It secured both these ends. California, which had been barely prevented from seceding in

1861, when it was isolated in space and interest from the States of the East, lost both the power and desire for such schemes when the railroads tied it in a vital connection with the rest of the country. The Indian tribes could no longer make war when the railroads enabled the army to concentrate rapidly at threatened points, and to make swift and thorough winter campaigns, not dependent upon grass for the cavalry horses or slow wagon-trains for the conveyance of camp supplies from some far-distant base.

But still another step was needed to complete the great work of the railroads. It was not enough to traverse the vast wilderness of barren mountains and deserts, or to make its ways safe for the pioneer. The mountains and deserts must be transformed from barriers to be surmounted into sources of wealth and homes of industry, so as to make the nation, not two communities, bound together in artificial connection, but one continuous empire, from sea to sea. To this end the first requisite was to disclose the natural resources of the region between the Missouri and the Sierra Nevada—above all, its mineral resources; for mining is the great pioneer industry, in the train of which all others follow. There never was, and probably there will never again be, such an amazingly rapid conquest of a continent as has been effected in forty years under what may be called the American system—the mining prospector going in the van as an irregular scout; the disciplined army of railroad-builders, surveyors, geologists and engineers close behind; and the representatives of agriculture, manufactures, education, political organization, social culture and religion following so swiftly that the whole army might almost be described as an advance without a rear-guard.

This spectacle, now familiar to us, was foreseen by a young man who could say, and make men believe, "The mountains of our great vacant interior are not barren, but full of wealth; the deserts are not all desert; the vast plains will produce something better than buffalo, namely, beef; there is water for irrigation, and land fit to receive it. All that is needed is to explore and declare the nature of the national domain."

And the same man could speak from personal knowledge of the region to which he called attention, and could appeal to the Engineer Department of the Army for testimony as to his

ability to carry out the work he proposed. The result, surprising then, and surprising still, was a generous appropriation by Congress for the geological survey of a strip of 100 miles on each side of the 40th parallel of latitude; in other words, of the belt containing the first Pacific railroad. The work was to continue three years, and was placed expressly under the charge of Clarence King (then 25 years old), subject only to the administrative control of Gen. A. A. Humphreys, Chief of Engineers of the U. S. Army—a brilliant topographical engineer as well as military commander, who appreciated the young explorer too thoroughly to interfere with his plans and methods.*

The difficulties and dangers of this work were not small. King's party, reaching California by way of Panama, spent three months in preparing its outfit and reaching its field. Many times it seemed as if portions of the scheme must be abandoned; but the leader's enthusiasm, energy and resource inspired his associates, and made them invincible. At the end of three years the work was not finished; but its success and value had been so brilliantly demonstrated that the period was extended to seven years, by the unsolicited action of Congress.

An incident reported by Mr. Emmons illustrates the courage and decision which belonged to King as one "born to command."

In 1868, during his field-work in Nevada, annoyed by frequent desertions from his cavalry escort—a small detail, under the charge of a sergeant—King resolved to make an example of the next case of the kind. The occasion was provided by a specially "bad man," who, while the party, engaged in their day's work, were absent from camp, fitted himself out with equipments belonging to the Survey, and "struck" for the Pacific coast, nearly twelve hours before he was missed. King and the sergeant started at once in pursuit. At about sunset

* The first legislation of Congress did not cover all this. It was simply a brief provision in an appropriation-bill, authorizing the application of certain unexpended remainders of former appropriations in the continuance of surveys for a transcontinental wagon-road. Upon this modest beginning, King won both popular and legislative recognition of his great enterprise.

of the next day the trail was seen to be heading for a natural pass in the next range (one of the short meridional ranges characteristic of Nevada). Leaving the trail, King and his companion, by a hard night-ride, made a detour over the mountain, and reached at sunrise the western outlet of the pass. Here he saw the fugitive's horse picketed near a willow thicket, which surrounded a spring, and in the middle of which the man himself was preparing his breakfast. King left his horse in the sergeant's charge and entered the thicket alone, with his "hair-trigger" Colt revolver. He afterward confessed that the situation required all his "nerve." The man, who was known as a desperate character, might have heard him coming and made preparation to shoot him at sight. But, after a minute of suspense, the climax was tame enough. The deserter, taken by surprise, was marched at the muzzle of King's pistol back to camp, and thence sent under guard to the military prison at Alcatraz—and there were no more desertions from that party. As for King's "nerve," it must have been little, if at all, disturbed; for a man cannot long keep his finger still on a hair-trigger, if he is agitated!

The following account of another of King's adventures is given by Mr. Emmons, an eye-witness and a participant:

"At the close of the field-work of 1871, King joined my party, which had been engaged through the summer in the Uinta mountains, for a tour of inspection along the northern frontier of that range. One day, as we were starting on an untried route across a piece of 'bad-land' country, we spied, soon after breaking camp, a grizzly bear in the distance; and all hands at once gave chase. The bear at first disappeared in a region of sand-dunes, where the party got scattered. After some hours' trailing, King, Wilson and I, with a couple of soldiers, ran the trail into a typical net-work of bad-land ravines—a series of narrow gullies with perpendicular walls, quite inaccessible for horses. Tying the heads of our five animals together (for there wasn't a bush big enough to hitch them to), we followed the huge, human-looking tracks down one ravine and up another on foot, each with rifle in hand, and King in the lead. (There was a pretended, but not thoroughly heartfelt, emulation to occupy this place!) Not only were we constantly turning sharp corners, but the trail would run into caves made by changes in the course of the dry stream-bed, which would continue for some distance under a bend in the wall of a gully. The bear evidently ran into many of these caves, passing out of each at the other end. Finally, four hours after starting, we had run him to ground. We had found a cave with his track going in at one end and not coming out at the other; and, by putting our ears against the bank, we could hear his labored breathing. The cave was unusually long—perhaps 30 or 40 ft. Its upper end, by which the bear had entered, was hardly more than a foot high; the other opening was high enough to be entered on hands and

knees. The grizzly could be only heard, not seen; but the sound indicated that he was nearer the upper end. Various attempts at dislodgment by smoking, etc., were unsuccessful; and finally King, who had poked his head far enough in at the upper end to see in the dark, said he could distinguish the animal's eyes, and would go in and shoot him. So I was stationed at the lower opening in case the bear should come out that way, and King wriggled himself into the little hole at the upper end, until he was far enough in to raise his body on one elbow and put his rifle to his shoulder. Even then he could not distinguish the form of the bear in the darkness; but he could see the gleam of its two eyes and feel its hot breath. Nor could he, at first, distinguish the sights of his rifle; but, after accustoming himself somewhat to the darkness, he aimed as best he could between the eyes, and fired. The big soldier who had been stationed for that purpose behind him, at once dragged him out by the heels, and, in his excitement, kept on dragging long after he had got his man out. As a result, King's face was badly scratched in the sand. We were not absolutely sure that the bear was dead; but, as there was no sound, I went into my end of the cave, and succeeded in getting a strap round its neck, by means of which and the combined and slow tugging of all hands we succeeded in dragging it into daylight. We then saw that King's ball had struck true, and penetrated the brain."

Mr. Hague contributes another reminiscence of King's self-possession under exciting circumstances. He was pursuing an elk, which finally turned and charged upon him. For a moment he was in considerable personal danger; but he came out victor, as usual. Listening, some time after, to King's story of the adventure, Hague said, "King, how did that elk look to you at the critical moment?" "Like a first-class hat-rack on a mule!" was the instant reply.

It was in the first or second year of my field-work as United States Commissioner of Mining Statistics that I made the acquaintance of Clarence King. He was at that time camped with a small party on a terrace overlooking the Salt Lake Valley, and invited me to dine with him in his camp. I had just come from a very rapid examination of some of the cañons in the Wasatch range, and he had been traversing the Uintah mountains further east. I remember the surprise with which I found him maintaining in the field, as far as possible, the decencies and elegancies of city life. Knowing of him as an explorer, hunter and athlete already famous, I could scarcely recognize my own expectation in the polished gentleman who, in immaculate linen, silk stockings, low shoes, and clothing without a wrinkle, received me at a dinner, simple enough in its material constituents, but served in a style which I had not found west of the Missouri. When I attempted to

make fun of him for "roughing it" in this way, he replied seriously: "It is all very well for you, who lead a civilized life nine or ten months in the year, and only get into the field for a few weeks at a time, to let yourself down to the pioneer-level, and disregard the small elegancies of dress and manners which you can afterwards easily resume, because you have not laid them aside long enough to forget them. But I, who have been for years constantly in the field, would have lost my good habits altogether if I had not taken every possible opportunity to practice them. We don't dine this way every day, but we do so whenever we can." I had abundant opportunity in after years to see King at work as well as at rest; and I never knew a man more eager, tireless and reckless in field-work above or underground, while at the same time he maintained always the instinct and practice of refined manners. It was, indeed, almost invariably his custom to have with him a personal attendant, who looked after his clothing, etc. One such, who was with him for years, came to be an invaluable assistant in geological underground work, observing with great acuteness, although without scientific knowledge, indications which more learned men might have overlooked. I cannot forbear an anecdote told me by King of another valet of his, whose life was in his work, and who judged of all things in the world by their relations to it. At a gentleman's country-seat, with good servants, accommodations, ample facilities for blacking boots and brushing clothing, well-trimmed lawns and genteel society, he was in Paradise; but experience in the muddy or dusty wilderness half paralyzed his usefulness and wholly quenched his enjoyment. On one occasion, attended by this man only, King made his way to the Grand Cañon of the Colorado, and stood for some time dumb upon its brink, overwhelmed with the vastness and the glory of the sublime and brilliant scene. At last it seemed to him that he must speak; and, as he turned away, he said, "Well, Joe, how does it strike you?" "It is no place for a gentleman, sir!" was the reply.

The most famous incident of the Fortieth Parallel Survey was the exposure by King of the "Diamond Swindle" of 1872. A full account of this episode will be found in the *Engineering and Mining Journal* of Dec. 10, 1872, together with my own editorial comments, based upon private knowledge as well as

published reports. The whole affair reflected the greatest credit upon King's personal honor and loyal friendship—its most creditable feature being the way in which he managed the exposure so as to prevent further loss by innocent investors, and, at the same time, to avert unmerited disgrace from equally innocent promoters and experts. By a sudden and sensational disclosure he might have won cheap distinction for himself, at the cost of cruel injustice to others.

Returning to the more serious and permanent significance of this part of King's career, I quote from Emmons's article in the *American Journal of Science* the following excellent summary:

"In recognition of the legitimacy of the public demand for a direct application of the results of government geological work, King pushed first to completion a scientific study of the ore-deposits of the region surveyed; more particularly of the great Comstock Lode, whose enormous silver product was then disturbing the monetary system of the country. This work, written conjointly by himself and James D. Hague, appeared as early as 1870 under the title of *Mining Industry*. It was described by one of its most capable critics as 'by itself a scientific manual of American precious metal mining and metallurgy.' It is considered classic among works in its line, and has served as a model for similar monographs which have since been published under government auspices and done so much to raise the mining industry of America to its present high position.

"In 1870 he discovered on the slopes of Mt. Shasta the first actual glaciers known to exist in the United States; and in their study made observations that are credited with first suggesting the true origin of the kettle-holes and kames of New England. His later discovery in the summer of 1874, that a line of islands along the southern coast of New England were a part of its terminal moraine, had much influence in inducing the later systematic studies of the Continental glacier.

"The field-work of the Survey was completed in 1873, but it was 1877 before the respective specialists had been able to work up the amount of material gathered, for it was one of King's fundamental principles that abundant collections should be made in the field to illustrate all the natural phenomena observed, and the lithological collections alone numbered about five thousand specimens.

"In 1874 he sent one member of his corps to Europe to study the methods of European geological surveys and to obtain the best and latest geological literature, with which at that time American libraries were but scantily provided. He also instructed him to confer with Prof. Zirkel, then the greatest microscopical petrographer of the day, and to induce him, if possible, to visit America and study in the presence of the collectors their collection of rock specimens, for at that time no American geologist had any practical knowledge of this new branch of geology. From this visit resulted Zirkel's volume on microscopical petrography, which marked the opening of a new era in geological study in the United States.

"King reserved for himself the final summarizing of the work of his assistants and the drawing of general conclusions and theoretical deductions therefrom. This he wrote in the winter of 1877–78, and published in a quarto volume of

more than 800 pages under the title of *Systematic Geology*. It has been characterized as the most masterly summary of a great piece of geological field-work that has ever been written, and is used to this day by university professors of geology as a model for their advanced students."

After two years of field-work had demonstrated the practicability of making geological maps in the unsettled regions of the west, another survey was inaugurated by the Engineer Department under the direction of Lieutenant George M. Wheeler, and the Hayden survey, already existing under the Department of the Interior, began the making of topographical maps as a basis for their geological work, and employed for this purpose the topographers of King's party after their term in that party had expired. These two surveys were not limited by law, like King's, to any particular region of the country, and each desired to get the most interesting part of the great west for its portion, partly because the survey of a district containing striking natural phenomena or exceptional mineral richness would bring special fame to the conductor, but also because the report of such a survey would constitute a very interesting public document, highly prized by congressmen for distribution to their constituents, and would powerfully assist in obtaining further appropriations from Congress for that particular work. This rivalry in the field and in the capital became at last so intense that there was serious danger of a reaction in Congress, cutting off all government aid for geological work. Mr. Emmons says:

"It was mainly through King's influence among the leading scientific men of the country and his tactful management of affairs in Congress that this crisis was averted. The question was referred to the National Academy of Sciences, and their recommendations, which were on lines laid down by him, were finally adopted by Congress, and on March 3, 1879, a law was passed establishing the United States Geological Survey as a bureau of the Interior Department. President Hayes, after consultation with the best scientists of the country, appointed Clarence King as the first director of the new Bureau. King accepted the appointment with the distinct understanding that he should remain at its head only long enough to appoint its staff, organize its work, and guide its forces into full activity. At the close of Hayes's term he offered his resignation, but at the President's request he held over until after the inauguration of Garfield. The latter accepted it on March 12, 1881, in an autograph letter, expressing in the warmest terms his appreciation of the efficiency of King's service and his regret that he did not find it possible to remain longer in charge of the Geological Bureau.

"Brief as was the duration of his administration, his influence, being exercised at the critical period of the Survey's existence, left a lasting impress upon it. He outlined the broad general principles upon which its work should be conducted, and its subsequent success has been in a great measure dependent upon the faithfulness with which these principles have been followed by his successors.

"Foreseeing the important part that the development of its mineral resources was destined to play in the future progress of the country, he judged that, while not neglecting the more purely scientific side, its work should be primarily devoted to the direct application of geological results to the development of these resources. It has been because the people at large have realized its practical success in this line that the Survey has been more richly endowed, and thus better able to carry on its purely scientific work, than any organization of its kind in the world.

"King set the very highest standard for its work, and showed remarkable judgment and knowledge of character in his selection of the men who, in their respective branches, were best fitted to keep it up, as nearly as possible, to this standard. In his establishment of a physical laboratory for the determination of the physical constants of rocks, he took a step in the direction of the application of methods of exact science to geological problems so far in advance of the average standards of the day that its importance was not generally realized until long after.

"In all his after life he maintained a lively interest in the work of the Survey, and kept closely in touch with his successors in office, who frequently consulted him on important questions of policy."

In another place, Mr. Emmons has spoken of the same period as follows:

"Although, owing to failing health, consequent upon the severe strain, both mental and physical, of nearly 20 years' strenuous work, he felt obliged to retire to private life in the second year of his directorship, he maintained the liveliest interest in the work and organization of the Survey up to the very last. . . . His belief was that a geological survey of a great industrial country, while not neglecting the more purely scientific side of its work, should occupy itself primarily with the direct application of geological results to the development of the mineral resources of the country.

"Under his direction were carried on the examinations of the Comstock, Eureka, Leadville and other mining districts, whose importance is to be measured not solely by the accurate information which they afforded of these particular regions, but in far greater degree by their influence upon the whole body of mining engineers, in teaching them the practical importance of a study of the geological relation of ore-deposits.

"He also planned and supervised the collection of statistics of the precious metals for the Tenth Census, a work which has never been equaled in detail or scientific accuracy, and whose logical result was the annual collection of statistics of all the mineral resources of the United States, which has been carried on by the Geological Survey ever since the completion of the work of the Tenth Census."

The great success and popularity of the United States Geological Survey has been due, without doubt, not only to the

liberal support of Congress, which King, more than any other one man, was able to influence, and to the wise organization and far-reaching plans which he impressed upon this institution in its creation, but also to the ability, loyalty, activity and intelligent enthusiasm of the young men who received their training under him during the Fortieth Parallel Survey, and many of whom have since won high reputation by their independent researches. The recent volume on "Ore-Deposits," published by this Institute, bears testimony to the extraordinary advance in that department of geological science in which American observers may fairly be said to have taken the lead. No doubt they have won this distinction largely by reason of three exceptionally favorable conditions, namely: the vast and rich field for investigation offered by the territory of the United States; the active development of this field by mining; and the liberal expenditures, both State and Federal, which have been made for the study of economic geology. But these favorable conditions would have amounted to nothing without the men competent to take advantage of them, and the wise provision made for such investigations by the first Director of the U. S. Geological Survey.

King's important contributions to scientific literature, apart from his work on the two public surveys already mentioned, were very few. Probably the most important were his address at the Sheffield Scientific School, in June, 1877, on "Catastrophism and the Evolution of Environment," and his paper on "The Age of the Earth," published Jan., 1893, in the *Am. Jour. of Science.*

The first of these was a *quasi* protest against the extreme uniformitarianism of the followers of Lyell, which he described (perhaps not quite fairly) as a theory that all geologic changes had taken place at "the harmless undestructive rate of to-day, prolonged backward into the deep past." I do not think Sir Charles Lyell would have controverted his main proposition that the evolution effected by the constant operation of known causes might, nevertheless, produce, and had in fact produced, more or less catastrophic changes. (To elucidate, by illustrations of my own, my notion of his meaning, I may cite the

effect of gradual increments of heat upon ice, which, at a certain point, suddenly turns into water,—or upon water, which likewise, at a certain point in the "uniformitarian" process, suddenly becomes steam. Or, as a general mathematical expression of the same law, the curve corresponding to a given formula may be "uniformitarian" up to a given point, and may then, in accordance with the same formula, present an abrupt and complete change of direction.)

This general proposition was so true as to be almost trite; but King gave it originality by illustrating it from the geological history of the American Cordilleran system, as developed by the Fortieth Parallel Survey.

As to "hypogeal fusion," King's hypothesis was that of a "critical" shell or *couche*, surrounding (or forming the outer portion of) the permanently solid interior mass of the earth, and having a temperature which would fuse it, but that its fusion is prevented (*i.e.*, its fusion-point is raised) by the pressure of the overlying rock. It would follow that when this pressure was diminished (as by rapid removal of the overlying weight) the rock thus relieved would become liquid, without necessary increase of its previous temperature, and local lakes of fusion would be thus created. Perhaps this ingenious suggestion might be called an application of Tyndall's well-known geyser-theory (which deals with the sudden vaporization of a liquid) to a case of sudden transit from the solid to the liquid form. Unfortunately, Tyndall's theory is not so perfectly satisfactory as it once was; and, besides, it includes a special sudden release of pressure (through the surface overflow from the geyser-column) which is not conceivable as part of an analogous process affecting solid rock.

Since the only general agency by which superincumbent rock could be removed was that of denudation (upheaval, in most cases, would not do, because it is not altitude, but the amount of weight preventing fusion, which can be effective under King's theory), the criticism was at once advanced by some of us that this theory practically involved the assumption that denudation (a process scarcely conceivable as catastrophically sudden) can go on at a greater rate than the cooling of a given buried layer of rock—which we thought highly improbable, though (somewhat to our surprise) we could not prove it to be

so. This objection King accepted with characteristic frankness—and relapsed into a significant silence, so far as public discussion was concerned. The secret (which he took no pains to explain to the scientific public) was, that he intended, before supporting his hypothesis by further argument, to provide himself with the precise data as to the rate of cooling by conduction through rock. We all knew (none better than he) that ice and congealed lava had lain for generations, perhaps for centuries, interstratified upon the slope of Etna; that "ice-caves" of the State of Washington showed how completely liquid lava could be protected from congelation by a rock-cover of moderate thickness; that the immense lava-streams of the Sandwich Islands, similarly protected by their own congealed sheaths, ran quietly for long distances under the sea; above all, that the interior cosmic heat of the earth is escaping at a very slow rate indeed. But, though all these observations point to an extremely small transmission of heat through rocks, nobody had fixed the actual rate of cooling for given conditions of weight and thickness of overlying rock.

In the chapter on Orography of his volume on "Systematic Geology" in the Fortieth Parallel series, King suggested his theory of the "critical shell," and said (p. 729), concerning it:

> "I can plainly see that, were the critical shell established, its reactions might thread the tangled maze of phenomena successfully; but I prefer to build no further until the underlying physics are worked out."

In pursuance of this conception, he established, in organizing the U. S. Geological Survey, a laboratory for terrestrial physics, contributing from his private means to its installation and continuance. The subtle and brilliant investigations pursued in that laboratory by Barus and Hallock are a part of the history of science, and have secured for these skillful observers much honor, well-deserved.* But, unless I am seriously mistaken, they have not yet determined for us the data which King desired as to the phenomena of the fusion and the heat-conductivity of rocks, under varying conditions of tempera-

* For instance, I have high authority for saying that modern scientific pyrometry is now wholly based on the platinum-rhodium and platinum-iridium couples, first described in the monographs from this laboratory. See, also, as a specimen of delicate work in terrestrial physics, Mr. Barus's paper, *Trans*, xiii., 417, on "The Electrical Activity of Ore-Bodies."

ture and pressure. At all events, I am not aware that King ever brought forward, in confirmation of his Sheffield address of 1877, any precise data of that kind. Meanwhile, the standpoint of his theory of a "critical shell" has been, perhaps, left behind in the progress of science—but on that head I need say nothing here. A man is not to be judged in the light of knowledge later than his own; and I heartily adopt the language of Mr. Iddings, who, in his *Origin of Igneous Rocks*, says of Clarence King that, by the breadth of his treatment, and by better and fuller data, he advanced the problem of the origin of the various kinds of igneous rocks far beyond the point reached by any of his predecessors.

King's intuition was not at fault when he recognized the igneous rocks as those concerning which existing scientific knowledge and opinion was least definite, and American geology could furnish most valuable information.* Not only intercourse with his friend Richthofen, a famous pioneer-observer in this field, but also his own wide travels in all parts of the United States and Mexico, as well as Europe, the Sandwich Islands, and Cuba, had made him specially acquainted with volcanic and cognate phenomena, and their results; and it was in this department of dynamic geology that he hoped to attach his name to a theory equally novel and fundamental.

So far as I am aware, the only result which he lived long enough to make known, of all this observation, study, preparation and patience, was his paper on "The Age of the Earth," already mentioned. This, I believe, he considered as a beginning of a series of geological applications of laboratory results, which he hoped to make. Mr. Emmons summarizes the treatise as follows:

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* In 1873, speaking to the German Congress of Miners and Geologists at Vienna, as President of the American Institute of Mining Engineers (and under the profound impressions made upon me by a recent reconnaissance of the great lava-plains of Oregon, Washington and Idaho, including the remarkable series of successive igneous and aqueo-igneous deposits of Cape Horn on the Columbia, the bluffs of the Des Schutes, and the long basaltic cañon of the Snake river), I told them plainly that no true perspective could be established for geology until the message of America concerning the plutonic rocks had been heard, verified, and incorporated among the fundamental bases of the science. The proposition, thus somewhat loosely and oratorically announced, was recognized much more intelligently by King, and has been confirmed and illustrated by American geologists, in the laudatory mention of whom, however, Vogt and Brügger of Norway must not be ignored.

"This was an attempt to advance to new precision Kelvin's estimate of the earth's age deduced from terrestrial refrigeration. It consists mainly of a mathematical discussion of the earth's thermal age as determined from various postulates presented by Laplace, George H. Darwin, and Lord Kelvin, and based on Barus's determinations of the latent heat of fusion, specific heat, melted and solid, and volume of expansion between the solid and melted state, of the rock diabase. This is followed by a critical examination of other methods of determining the earth's age—by tidal retardation, by sun-age, and by variations of eccentricity. After a careful scrutiny of all the data on the effect of pressure on the temperature of consolidation, King concluded that, without further experimental data, 'we have no warrant for extending the earth's age beyond 24 millions of years,' an estimate which, as the result of a somewhat more extended discussion, was afterwards confirmed by Lord Kelvin himself (*Smithsonian Ann. Rept.*, 1897, p. 345).

I know that King considered the praise of this work by Lord Kelvin as one of the greatest honors ever bestowed upon him.

To general literature he contributed one delightful book, "Mountaineering in the Sierra Nevada," and a few magazine articles. The book describes the scenery and the people encountered by him in his early California experiences, and has never been surpassed as a gallery of vivid, graceful, and imaginative yet accurate sketches of nature and men. Bret Harte's admirable work is more romantic, more artificial, less delicately humorous, and less perfect in style. Indeed, considering the relatively small amount of King's literary work, his mastery of style was wonderful. Perhaps the most perfect specimen of it was his fanciful sketch, "The Helmet of Mambrino," published in the *Century*.

Doubtless one reason why he did not publish more was, as Mr. Emmons suggests, his fastidious taste, which led him to be dissatisfied with anything less than the best work. But this is not, to me, a full explanation. The possessor of such a gift of expression, and so rich a repertory of knowledge, and suggestions waiting for utterance, usually feels, also, the spontaneous impulse to make use of them. King was not an exception. He talked often of things he would like to write, and intended to write, some day. But he never found time for such labors, partly because of the exigent social demands made upon him; partly because of the necessity for more active and arduous occupation, to which he was repeatedly, if not continuously, subject. A man can do literary work in his stolen leisure, and yet be a darling of society, shining brightly in the club and at

the dinner-table; or he may be active in business and professional engagements, and still keep enough time and strength for quieter pursuits. But he cannot be and do all three. King, especially, could not do this, because his brilliant talk exercised and fatigued the same faculties as if it had been pen-work. If he felt the impulse of utterance he wore it out in talking, and often threw away upon the transitory entertainment of a few what might have been the enduring delight of a multitude. An instance was furnished by a dinner-party in Washington, just before the outbreak of the late Spanish war, at which King was present, and expressed with vivacity his views and expectations. He had lived in Cuba, was intimate with some of the patriot leaders there, and was thoroughly acquainted with their plans and campaigns.* But he had also sailed the Pacific, and had an intelligent notion of the situation in the far East, of which few of us were specially thinking at that time. And his prediction was this: "If war is declared with Spain, the first thing to happen will be that George Dewey will go into Manila harbor and sink the whole Spanish fleet!" If he had put that day's talk in print, with what prophet's glory it would have crowned him! Long after, he said to me, "I was a little startled to have the thing so quickly and completely come to pass; yet I made the remark upon good reasons. I had lived with Dewey, and knew him well; I knew where he was, and that he could not stay there after a declaration of war; if he had to go somewhere, he would be sure to go where the Spanish fleet was; and if he found it, he would sink it! You see, the argument was complete!"

After all, the chief hindrance to King's literary activity was the necessity of earning money in his profession. Several times in the course of his life he suffered financial reverses, which forced him practically to begin over again, and to work as a mining engineer in the field—sometimes directing or advising, sometimes valuing, sometimes buying and selling. Of three companies which opened respectively,—the Las Prietas

* See his *Forum* articles, "Shall Cuba be Free?" and "Fire and Sword in Cuba."

mine, in Sonora, the Las Yedras, in Sinaloa, and the Sombrerete, in Zacatecas,—he was the president; and he was actively connected with the Richmond, at Eureka, Nevada, and other American mines.

On many occasions he was engaged as an expert witness in mining law-suits. I need hardly say that, while he was in the service of the United States, he gave no such assistance to private interests. Indeed, he was quick to perceive that the members of the public scientific surveys must be kept free from any suspicion of utilizing, for the benefit of any party smaller than the whole of a mining community, the knowledge gained in that capacity; and he exacted from every subordinate a pledge in this particular, corresponding with his own practice. But when not thus honorably bound, he repeatedly acted as adviser, or gave expert testimony, for clients. In this line, having both encountered Mr. King as an opponent and benefited by his assistance as a colleague, I may claim to be qualified as a critic of his work—or rather of his character, as shown by his work.

In the first place, he was, as I think an expert witness ought to be, an honest partisan. He did not carry to the witness-stand the doubts or uncertainties which he might have felt during his previous study of the case. He came forward with a theory already deliberately adopted, and for that theory (in the absence of new evidence disproving it) he was prepared to fight.

But this final temper and attitude had the indispensable safeguard of an inexhaustible curiosity and candor in previous inquiry. I have known, in my time, many mining experts, and their personal methods of studying mining cases. But I never met King's equal in insatiable desire to find out beforehand anything that anybody else knew or could know, whether it were relevant and important to the case in hand or not. I can remember him as going into a mine at early morning, taking his lunch with him; coming out late in the afternoon; bathing and dressing for dinner; then, aroused by some casual table-talk, putting on his underground clothes again, and spending the greater part of the night in the mine, just to "settle the point"—though the point was not perceptibly pertinent to the immediate case in which he was engaged.

In general, his exhaustive preparation and wonderful general knowledge, reinforced by his alert self-possession, ready wit and unfailing good-nature, made him a most effective expert witness and a terror to cross-examiners.

After retiring from the U. S. Geological Survey, King spent three years (1882, '83 and '84) studying the geology of Scotland, Switzerland and Central Europe, occasionally visiting a mining district, like Bilbao, Rio Tinto or Almaden, and enjoying the social courtesies eagerly extended to him by the leaders of scientific thought, to whom his work had already made him known and his charming personality soon endeared him.

At a later period, after recovery from a severe illness, he spent a winter in Cuba, at the country-house of an American friend, and became deeply interested not only in the politics, but also in the general and economic geology of that island, examining particularly some of the important iron and manganese deposits of the Santiago district. He conceived a high opinion of the mineral wealth of Cuba; and it was at least his dream, if not his definite intention and hope, that some day, when Cuba should be free, he would organize for that field, as he had done for a greater, a national geological survey.

I notice that Mr. Emmons* dates the final illness of Clarence King from an attack of pneumonia in 1901. From personal knowledge, I would put the beginning further back. During the spring of 1900 I was associated with King in the long trial of a case at Butte, Montana. The season was unusually mild, and the atmosphere of Butte unusually clear. Perhaps these balmy conditions tempted people to imprudent exposure. At all events, the town was afflicted with a veritable pestilence of pneumonia. In popular rumor the fatality was 90 per cent.; in actual statistics it was 54 per cent. of all the victims attacked. Among the counsel, parties and witnesses in our case, or in their families, eleven died during the trial. King prepared himself with his usual pertinacity and industry, spending many hours underground, and taking prudent precautions against chills; but he had an annoying hoarseness,

* In his article in the *Am. Jour. of Sci.*, already cited, p. 237.

which he could not shake off. After giving his testimony he made a rapid trip to Salt Lake, for change of air and altitude, and in a couple of weeks returned, still uncomfortable, though not alarmed. But by that time the rest of us were anxious for him, and, against his will, made him consult a physician, who put him to bed instantly. This prompt measure saved him from a serious illness; but the escape was a narrow one, as he was willing to acknowledge after a few days' confinement. He was not allowed to take further part in the trial, and it was over before he was able to leave his room. When he told me that he expected to go to the Klondike that summer, I felt a thrill of apprehension, and ventured a remonstrance. But, like all habitually healthy people, he thought nothing more of a temporary illness, once it was over; and to the Klondike he went, with the seeds of pulmonary trouble already sown in him. And after the exposures of the Klondike trip he had a second and severe attack of pneumonia, brought on in 1901 by a fresh exposure during the examination of a mining property in inclement weather. From that time, the progress of tuberculosis was rapid and irresistible. With superb courage and calmness he fought to the end the hopeless battle, seeking in vain, at Prescott and Los Angeles, cure of his malady, and finally returning from Southern California to Phœnix, Arizona, where he died without pain, December 24, 1901. With characteristic unselfishness he had refused all offers of companionship from friends or relatives, and made his last brave fight alone.

Many, no doubt, have had ampler and more continuous association with Clarence King than I enjoyed during the one-third of a century covered by our unbroken friendship. He was one who could pick up, after any lapse of time, however long, the associations and reciprocities of the past, and make the intervening separation seem not to have been at all. However one might have been offended by his neglect to answer letters, or let himself be heard from in any way, five minutes of his presence was enough to show that the old friend, unchanged, had come to see the old friend, expecting an unchanged welcome. And what he expected, he received. I never heard of anybody who refused to forgive Clarence King

for neglect of conventional obligations—and I fancy all who knew him had occasion for such forgiveness. My own theory of the matter is, that he was so universally beloved, and responded so easily to congenial companions, as to make it impossible for him to keep up, by the usual means of visits, letters, etc., the innumerable ties which he thus formed, without sacrificing all the more serious labors and ambitions of his life. A man can forswear society altogether and do his life's work; or he can give himself up to society and let his work go. King took a middle course, continuing to study and to labor, while he freely gave and received social enjoyment, but defied the engrossing demands of formal etiquette. And "society" forgave him, because it could not have him on any other terms.

But perhaps it was given to me, in hours of unconstrained communion, to gain a deeper glimpse into his character than many days of mere superficial association could have given. And I found him clean to the bottom; full of noble scorn for things trivial, vile and selfish; alive to the highest ideals; ready for the service of human needs.

It was in such an hour that he told me (veiling with a transparent whimsical humor of narration his earnest feeling) of his "Sunday-school" in London, where he used to meet, on Sunday afternoons, the girls employed in Crosse & Blackwell's famous pickle-factory, and talk to them in fashion "not quite orthodox, perhaps, but then, again, not so awfully heterodox either!"—and how, finding his Sunday-school utterly ignorant of the beauties and joys of green grass and flowers, he organized an excursion for them, securing, by unlimited use of his aristocratic acquaintances, unprecedented privileges for it, so that his delighted protégés, conveyed and convoyed by him on a special train, not only had afternoon tea on the lawn in Windsor Park, but the dear old Queen herself came out of the palace, walked among them, and accepted a cup of tea from a proud member of the company! King's witty account of his "happy hen-party" I cannot undertake to reproduce. But there was for me something dearer and deeper in it than its sparkling surface.

Few among those who have achieved distinction in the labors or the literature of science have also impressed upon their gen-

eration a vivid sense of their own personality. In the majority of instances, I think, such men have hid themselves in their work, sacrificing to it the varied enjoyments and associations through which they might have become better known to their contemporaries. Perhaps we might say that, in this age, scientific distinction must be won, as a rule, in some specialty, and at the cost of an exclusive devotion to that one department; so that the great specialist, however versatile he might have become, if all his original endowments had been utilized, is at last, to the eyes of men, simply the impersonal representative of one idea or sphere. On this point we have the frank, pathetic confession of Darwin, that many æsthetic faculties and tastes, once his, became atrophied in the course of years devoted to a single study. After the death of such a man, a sympathetic biographer may lift the veil and show to all what had been known before to few,—his personal traits and charms; thus filling up with detail and color the hard, meager outline of him presented by his special work alone.

Clarence King did not thus sacrifice himself to his work. His buoyant personality dominated his whole career. Gay, versatile, debonair, irresistible, gentle, honorable, "tender and true," he was greater and dearer than his work. We shall have, as we have had, many prophets and pioneers of science; but the King is dead—and there is no King to follow!

The following list comprises the principal published works of Clarence King:

"Mountaineering in the Sierra Nevada," Boston, 1870.

"Mining Industry" (by James D. Hague, with geological contributions by Clarence King), vol. iii. of the Fortieth Parallel Reports—Government Printing Office, Washington, 1870.

"Active Glaciers within the United States." Atlantic Monthly, March, 1871.

"On the Discovery of Actual Glaciers on the Mountains of the Pacific Slope," Am. Jour. Sci., 3d Ser., vol. i., p. 157, 1871.

"Notes on Observed Glacial Phenomena and the Terminal Moraine of the N. E. Glacier," Proc. Boston Soc. Nat. Hist., vol. xix., p. 60, 1876.

"Paleozoic Subdivisions on the Fortieth Parallel," Am. Jour. Sci., 3d Ser., vol. xi., p. 475, 1876.

"Notes on the Uinta and Wahsatch Ranges," Ibid., p. 494.

"Catastrophism and Evolution," Am. Nat., vol. xi., p. 449, 1877.

"Systematic Geology," vol. i. of the Fortieth Parallel Reports, Government Printing Office, Washington, 1878.

"First Annual Report of the U. S. Geological Survey," Government Printing Office, Washington, 1880.

"Physical Constants of Rocks," U. S. Geol. Survey, 3d Ann. Report, p. 3, Government Printing Office, Washington, 1883.

"Style and the Monument," North Am. Review, Nov., 1885. (An article on the proposed Grant monument—anonymous, but known by friends of Mr. King to have been written by him.)

"Artium Magister," North Am. Review, Oct., 1888.

"The Age of the Earth," Amer. Jour. Sci., 3d Ser., vol. xlv., Jan., 1893.

"The Helmet of Mambrino," Century, p. 154, May, 1886.

"The Biographers of Lincoln," Century, p. 861, Oct., 1886.

"The Education of the Future," Forum, p. 20, March, 1892.

"Shall Cuba be Free?" Forum, p. 50, Sept., 1895.

"Fire and Sword in Cuba," Forum, p. 31, Sept., 1896.

Mining and Metallurgy at the St. Louis World's Fair, 1904.

BY PROF. JOSEPH A. HOLMES, ST. LOUIS, MO.

(New Haven Meeting, October, 1902.)

THE public is already familiar with the general fact that the scope and the financial resources of the approaching St. Louis World's Fair are much larger than those of any of the preceding great expositions; and both the visitor and the exhibitor, when he comes to St. Louis in 1904, will find it to be a real World's Fair, with exhibits and visitors from every known country.

Passing over the subject, as to the general Exposition, with this brief statement, I ask your attention to the consideration of a few important facts connected with the proposed mining exhibits at this Exposition. First of all, I may say that reading- and writing-rooms and library facilities will be furnished in the Mines Building for miners and mining engineers, and it is expected that when they visit the Exposition they will make these rooms their headquarters, and give the Chief of the Department and his assistants an opportunity to extend to them such courtesies as may be possible.

One of the exhibits in the Mines Department will consist of models and maps arranged to show the nature and extent of the mining operations in the United States at the time of the purchase of the Louisiana Territory in 1803, the event which

this Exposition commemorates. Of course, the industry was then in its infancy, and the exhibit will necessarily be a small one. But since that time the United States has expanded underground almost as rapidly as it has above ground. It will be one of the great purposes of the Mines Department of the Exposition to show the nature and extent of this underground expansion, the equipment used in the mining operations of to-day, and the metallurgical equipment and processes employed in the preparation of these mineral products for use by the people at the present time. Hence, the larger part of the exhibits in the American section of the Mines Department will be arranged so as to show the condition of the mineral industry as it is to-day, and to illustrate its development during the intervening century. Of course many of these processes are so complicated and extensive that they can only be represented by models and photographs, but all those which will lend themselves to treatment on a small scale will be shown at the Exposition in actual operation.

The exhibits of the Department will be divided into five groups, and these, in turn, are divided into fifty-three classes.

In the first of these groups it is intended to show equipment and processes connected with the working of mines, ore-beds and stone-quarries. This will include equipment and methods used in prospecting for mineral deposits; in making geological surveys; in testing and assaying ores and other mineral substances; in opening up, timbering, draining and ventilating mines; and equipment for underground and aboveground transportation for ores.

The second of these groups of our classification will contain the collections of rocks and minerals, supplemented by exhibits illustrating the equipment and processes employed in preparing this material for actual use, and the products into which they are manufactured. Another group of exhibits will illustrate the whole subject of metallurgy, including the processes employed in the transformation of these ores into their respective metals. In this, special prominence will be given to the metallurgy of iron and steel; but prominence will also be given to other important metals, and to the alloys of these various metals. Some of these exhibits will also endeavor to illustrate general foundry equipment and processes, and the processes

connected with the use of electricity, gas, petroleum and other fuels in metallurgical operations; and the equipment and processes connected with electro-plating, and other uses of electricity in mining and metallurgy.

The two remaining groups of exhibits will include models, maps and photographs of mines, quarries, metallurgical and mining equipment, and the literature relating to quarrying, metallurgy, geology, etc.

The exhibits of specimens of rocks and minerals and ores illustrating the resources of this and other countries will be made largely under the official Government and State Commissions, as heretofore; but we shall require that every such specimen brought into the Mines Building at the Exposition must be accompanied by labels, maps, photographs, charts, etc., giving accurate information as to the real ore or mineral-deposits which such specimens represent; and, in order to accomplish this result in the most satisfactory manner, we are endeavoring to secure the active co-operation of the State and other local geologists and mining engineers with the State Commission in the collection and preparation of these exhibits.

The exhibits illustrating the metallurgical and other processes through which these metals and other minerals and stone are utilized will be made largely by individuals and private corporations, and we are endeavoring to have these as complete and elaborate as possible. Thus, for example, in connection with the lead industry, all the important processes will be shown from the crushing of the ore down to the manufacture of shot. For zinc, copper and gold, the metallurgical processes will be shown in practically the same degree of completeness. In the iron and steel industry, the more important actual metallurgical operations cannot, of course, be shown, but these will be indicated by specimens, models, photographs, charts, etc., in a way becoming this greatest of our mineral industries.

The Mines Building at the Exposition will cover about nine acres; and it is so well arranged that practically the entire space, except that occupied by walls, is easily available for exhibits. It promises to be the most beautiful building on the grounds, and its location is in every way satisfactory. On one side of it, for a considerable portion of its length, the ground

rises gently to a height of 40 ft. above its floor; and underground tunnels can be run into this hill to illustrate methods of tunneling, timbering, and the underground transportation and handling of ores in the most satisfactory manner. On the ground adjacent to the building is an additional area of ten acres for such out-of-door exhibits as will illustrate the drilling of oil-wells, the operation of stamp-mills, the hydraulicking of placer-deposits, etc.

In brief, as far as this may be possible of attainment, these exhibits are all planned and will be installed with a view of having them tell the whole story as to our mineral resources; how they are mined and brought to the surface; how they are transformed by the metallurgist and manufacturer, and thus made ready for use by the people.

In the mineral and mining exhibits from each foreign country, we are asking that special prominence shall be given to those branches of mining industry which are prominent in that special country, and also those which are largely exported from that country. And in the metallurgical exhibits from each of these countries, we are asking that each country's exhibit shall show especially the processes and products in those branches of metallurgy which are being largely promoted and developed in that country.

The Elimination of Arsenic, Antimony and Bismuth from Copper.

BY ALLAN GIBB, MOUNT PERRY, QUEENSLAND, AUSTRALIA.

(New Haven Meeting, October, 1902.)

THE ores of copper are usually associated with minerals containing arsenic, antimony and bismuth. Whatever the means adopted for extracting the copper, these metals are usually found, to a greater or less extent, in the product. There is, however, usually some elimination in the various metallurgical operations to which the ores are subjected, and some attempt is made here to determine the degree to which this elimination is effected.

The degree, as well as the cause, of the elimination varies considerably with the amount of impurity in the material under treatment, and the results given here can only be taken as conclusive in the case of such materials as have come under the writer's observation. The conclusions have, however, been drawn from the study of large quantities of materials that may be considered as fairly typical.

Elimination may take place in the smelting operations by scorification, volatilization, or, under special treatment, by processes of concentration. Owing to the great variety of materials that are treated in economical metallurgy, it is rarely possible to obtain exact weights from any particular operation. It is, consequently, a matter of some difficulty to obtain data that will show how elimination has taken place. In much of the following work the writer has had to be satisfied with determining the relative elimination of the impurity under consideration. In only a few cases have I been able to obtain exact weights, etc., of products.

Roasting of Copper-Ores.

This operation may be carried on in heaps or stalls, when the ore is treated in the form of lumps, or in closed furnaces into which the ore is introduced in the form of a powder. The action of heat and air in the elimination of the elements under consideration appears to be the same in either case.

Arsenic, when present in sulphides, in arsenides, or in the metallic state, volatilizes at incipient redness as arsenious sulphide or as metal, or it is oxidized to arsenious oxide, which is readily volatilized. Arsenates, mainly those of iron and copper, are formed by the oxidation of both elements of the metallic arsenides, and by the action of atmospheric oxygen and arsenious oxide upon metallic oxides. These salts, as well as any similar compounds that may be present in the ores under treatment, are fixed at the highest temperatures. Arsenates may possibly be reduced by the action of sulphur and sulphides with the production of sulphides, arsenides or arsenites, and under the action of air these may be volatilized. But as this reducing action is in every case endothermic, it is very unlikely to take place under the conditions of low temperature and oxidation pertaining to the roasting operation. In point of

fact, the arsenic remaining in calcined ores consists largely of metallic arsenates.

Antimony is, to a great extent, similar to arsenic in its occurrence in copper-ores, and also in its deportment when subjected to the action of heat and air. It volatilizes as a sulphide and as metallic antimony, but to a less extent than the corresponding compounds of arsenic. Metallic antimonates are probably formed in greater proportion to the amount of the impurity present than in the case of arsenic, and are fixed at all temperatures.

Bismuth may be present in the metallic state or in sulphides, arsenides and antimonides. The metal and sulphides are volatile at the roasting temperatures, but much less readily than in the cases of arsenic and antimony. The minerals containing bismuth are readily oxidized to fixed compounds.

The roasting of copper-ores preparatory to smelting is always incomplete. Arsenic, antimony and bismuth may remain in the roasted product in the same combinations in which they occurred in the ores, accompanying the fixed compounds that are formed during the operation.

The degree of elimination of these impurities in this operation varies, necessarily, with the minerals in which they occur, as well as the copper-ore, and the conditions under which the operation is carried on. The following analytical data show the elimination from fairly typical ores when roasted in heaps and in closed furnaces.

Roasting Ores—Elimination of Arsenic, Antimony and Bismuth.

	Raw Ore.		Calcined Ore.		Elimination per 100 of Copper.	Total Percentage of Elimination
	Per Cent. Actual.	Per Cent. Relative. Copper=100.	Per Cent. Actual.	Per Cent. Relative. Copper=100.		
1.						
Copper.......	5.55	100.00	7.68	100.00	....	....
Arsenic......	1.18	21.26	0.407	5.29	15.97	75.1
Antimony...	0.035	0.63	0.035	0.47	0.160	25.4
Bismuth.....	0.011	0.198	0.011	0.143	0.055	27.8
2.						
Copper.......	12.15	100.00	14.68	100.00	....	....
Arsenic......	0.967	7.96	0.454	3.09	4.87	61.2
Antimony...	0.046	0.378	0.045	0.307	0.071	18.8
Bismuth.....	0.014	0.115	0.015	0.102	0.013	11.3

No. 1 was a cupreous iron pyrites which was roasted in heaps and subsequently smelted in a blast-furnace. No. 2 was a dressed ore containing copper, mainly in the form of copper pyrites, with smaller proportions of bornite and copper-glance. It was calcined in a reverberatory furnace.

In both ores, as is usually the case with sulphuretted ores, the proportion of arsenic is much larger than that of either antimony or bismuth. From the table it will be seen that the elimination of arsenic is considerably greater, in proportion to the original amount contained, than is the case with either antimony or bismuth.

Smelting Calcined Ores.

In this operation there is a distinct difference in the action of the reverberatory and the blast-furnace. The atmosphere in the reverberatory furnace is always oxidizing, and the reactions that take place in melting calcined ores are (except in so far as they form a continuation of the roasting operation) only such as take place between the constituents of the ore. Arsenates heated strongly with silica are decomposed with the formation of metallic silicates, oxygen and arsenious oxide. Silica usually being present in the furnace-charge, arsenic may be eliminated by this action. Ter-sulphides of arsenic and bismuth remaining in the calcined ore may be volatilized when heated to the smelting temperature. Arsenates or antimonates and fixed oxides of these elements combine, in notable proportions, with the slag-forming elements. Arsenic and antimony are often present in considerable proportions in the slags from reverberatory furnaces smelting calcined ores.

The conditions are different in the blast-furnace when smelting calcined ores, as the gases are of a reducing character. The larger part of the arsenates and antimonates are probably reduced to arsenides and antimonides. These combine with the sulphides of iron and copper, forming the regulus, while the resulting slags contain none, or only minute traces, of these elements. Arsenic and antimony are probably volatilized as sulphides, but the greater part of both is concentrated in the resulting regulus. Bismuth and its sulphides, which may be reduced from the oxides and sulphates formed in the calcination, are volatilized in considerable proportions during the

smelting operation. Furnace slags, whether produced in the blast-furnace or in reverberatory furnace are, so far as they have come under the writer's observation, practically free from bismuth. The following analytical data were obtained from calcined ores and the regulus resulting from smelting in the two classes of furnaces.

Smelting Calcined Ores in Reverberatory Furnaces—Elimination of Arsenic, Antimony and Bismuth.

	Calcined Ore.		Coarse Metal.		Elimination per 100 of Copper.	Total Percentage of Elimination.
1.	Per Cent. Actual.	Per Cent. Relative. Copper=100	Per Cent. Actual.	Per Cent. Relative. Copper=100.		
Copper.......	10.60	100.00	37.0	100.00	....	....
Arsenic......	0.102	0.96	0.132	0.357	0.603	62.8
Antimony..	0.025	0.236	0.037	0.10	0.136	57.6
Bismuth.....	0.010	0.094	0.028	0.075	0.019	20.2
2.						
Copper.......	14.40	100.00	35.28	100.00	....	....
Arsenic......	0.33	2.29	0.185	0.524	1.766	77.1
Antimony...	0.050	0.347	0.04	0.113	0.234	67.4
Bismuth.....	0.014	0.097	0.025	0.070	0.027	27.8

Smelting Calcined Ores in Blast-Furnaces—Elimination of Arsenic, Antimony and Bismuth.

	Calcined Ore.		Coarse Metal.		Elimination per 100 of Copper.	Total Percentage of Elimination.
	Per Cent. Actual.	Per Cent. Relative. Copper=100.	Per Cent. Actual.	Per Cent. Relative. Copper=100.		
Copper.......	10.60	100.00	32.5	100.00	....	....
Arsenic......	0.102	0.960	0.231	0.710	0.25	26.1
Antimony...	0.025	0.236	0.056	0.172	0.064	27.1
Bismuth.....	0.01	0.094	0.015	0.046	0.048	51.0

In smelting calcined ores, arsenic, antimony and bismuth are, as has been already explained, only partially concentrated in the regulus known as coarse metal. The elimination of these elements, effected by volatilization and scorification, could have only been deduced from the analyses of the ores, regulus and slags from the same operation, or series of operations, in the same furnace. In the absence of these complete data it is only possible, as in the above table, to show the total

elimination. The relative proportions in which the metals occur in the slags from this operation, however, enable us to deduce, to some extent, the relative effect of the two agencies to which the elimination is due. In examining the slags from reverberatory furnaces smelting ores containing arsenic and antimony, I have never failed to find these metals,—arsenic in various amounts up to 0.4 per cent., and antimony up to 0.06 per cent. In the examples of reverberatory practice given in the above tables the proportion of slag formed would be, respectively, about six times and four times as much as the copper in the ore, so that the presence of considerably smaller proportions of arsenic and antimony than those mentioned would account for the total elimination deduced from the analysis. It is therefore probable that only a small proportion (in some cases practically none) of the arsenic and antimony is eliminated by volatilization in reverberatory practice. The elimination of arsenic and antimony in this operation is considerably greater than that of bismuth.

In the case of slags produced from blast-furnace practice, smelting similar materials, I have never found more than 0.015 per cent. of arsenic, and only traces of antimony. It is, therefore, probable that the elimination of these elements in blast-furnace practice is almost entirely due to volatilization. On no occasion have I found more than traces of bismuth in ore-slags, whether produced in blast- or reverberatory furnaces, so that its elimination, which in the blast-furnace is considerable, may be taken as resulting entirely from volatilization.

Calcining Coarse Metal.

Arsenic, antimony and bismuth are more uniformly diffused in coarse metal than in the ore, where they occur in separate intermixed minerals. In coarse metal these elements probably exist entirely as sulphides, uniformly diffused through a comparatively large proportion of regulus, and their behavior under calcination differs notably from that of the minerals rich in these elements mixed with copper-ores. The annexed analytical data show to what extent elimination is effected from coarse metal containing arsenic, antimony and bismuth in proportions fairly representing the product obtained from smelting the ores that usually reach the United Kingdom.

Calcination of Coarse Metal—Elimination of Arsenic, Antimony and Bismuth.

	Raw Coarse Metal.		Calcined Coarse Metal.		Elimination per 100 of Copper.	Total Percentage of Elimination.
	Per Cent. Actual.	Per Cent. Relative. Copper=100.	Per Cent. Actual.	Per Cent. Relative. Copper=100.		
Copper.......	33.40	100.00	31.04	100.00	....	....
Arsenic......	0.185	0.554	0.111	0.358	0.196	35.4
Antimony...	0.060	0.180	0.062	0.200	Nil	Nil
Bismuth.....	0.017	0.051	0.013	0.042	0.009	17.6

The above table shows that, in the coarse metal under consideration, over one-third of its arsenic and about one-sixth of its bismuth were volatilized during calcination, while the calcined product retained all the antimony.

Arsenic is probably partly oxidized and volatilized as arsenious oxide. The elimination, however, is less marked than in calcining ores, in which the arsenic is mainly present in minerals associated with the copper-ore, but not in combination with the bulk of the copper. These minerals are readily decomposed by heating with air, or *per se*, giving off arsenic as oxide, sulphide and metal. In coarse metal, on the contrary, all the arsenic is probably combined with the sulphur, and is diffused through the whole mass of regulus in comparatively small proportion. In the earlier stages of the operation arsenic is probably volatilized as oxide. But, as the operation proceeds, metallic oxides increase in quantity and the conditions become more favorable for the formation of metallic arsenates, which remain fixed in the product of calcination.

Antimony is not volatilized in appreciable quantity during calcination. It is more or less completely oxidized to form metallic antimonates which are fixed at the temperature of the calcination.

Bismuth is probably partly volatilized as sulphide, but its oxides, formed during calcination, remain in the calcined product.

Smelting Calcined Coarse Metal.

In smelting calcined coarse metal in the reverberatory furnace for the production of white metal, the three elements

under consideration are eliminated to a considerable extent. The slags from this operation contain notable quantities of arsenic and antimony. These amounts vary with the proportions present in the material under treatment, which consists of calcined coarse metal and slags from the roasting and refining furnaces. The slags from this operation, under ordinary conditions, often contain 0.50 per cent. of arsenic and 0.10 per cent. of antimony. In smelting calcined coarse metal, containing 31 per cent. of copper, to white metal, its iron and the siliceous earthy matter derived from the furnace give a slag about equal to twice the weight of its copper contents. In the following data the elimination from metal containing 100 of copper is seen to be 0.209 of arsenic and 0.118 of antimony, which would represent 0.104 per cent. of arsenic and 0.059 per cent. of antimony on the slag produced, so that it is probable that the greater part of the eliminated arsenic and antimony are present in the slag.

In the case of bismuth the elimination is practically effected by volatilization alone. The slags from ordinary materials never have more than 0.02 per cent. of bismuth.

In smelting roasted coarse metal in the blast-furnace the slags are practically free from arsenic, antimony and bismuth, so that the total amount of these elements eliminated may be taken as volatilized.

The elimination in blast-furnace smelting as compared with smelting in reverberatory furnaces is only about one-third in the case of arsenic and antimony. It is about one-eighth more in the case of bismuth. These comparative results are similar to those found in smelting calcined ores.

Smelting Calcined Coarse Metal—Elimination of Arsenic, Antimony and Bismuth.

1. *In reverberatory furnaces.*

	Calcined Coarse Metal.		White Metal.		Elimination per 100 of Copper.	Total Percentage of Elimination.
	Per Cent. Actual.	Per Cent. Relative. Copper=100.	Per Cent. Actual.	Per Cent. Relative. Copper=100.		
Copper......	31.04	100.00	74.34	100.00	....	....
Arsenic......	0.111	0.358	0.111	0.149	0.209	58.5
Antimony...	0.062	0.20	0.061	0.082	0.118	59.0
Bismuth.....	0.013	0.042	0.020	0.027	0.015	35.7

2. *In blast-furnaces.*

	Calcined Coarse Metal.		Blue Metal.		Elimination per 100 of Copper.	Total Percentage of Elimination.
	Per Cent. Actual.	Per Cent. Relative. Copper=100.	Per Cent. Actual.	Per Cent. Relative. Copper=100.		
Copper.......	31.82	100.00	63.50	100.00	....	....
Arsenic......	0.136	0.427	0.216	0.340	0.087	20.4
Antimony...	0.061	0.192	0.094	0.148	0.044	22.9
Bismuth.....	0.014	0.044	0.016	0.025	0.019	43.2

Roasting White Metal to Blister-Copper.

In roasting white metal, oxidation of cuprous sulphide and mutual reduction of the oxides and sulphides of copper may be said to proceed together at a high temperature. Oxidation of arsenic and antimony, and their volatilization as oxides, probably goes on during the scorification in which the two oxides combine with the cuprous oxide formed in the operation. The analytical results of the examination of white metal, blister-copper and slag produced in its roasting show that, of the arsenic eliminated, about equal proportions have been volatilized and scorified; while the proportion of antimony scorified is greater than that volatilized. Bismuth is scorified only to the extent of one-eighth of the amount present, while about three-fourths of the whole quantity is eliminated by volatilization.

In the tables on p. 662 the blister-copper and slag are calculated from working-results in treating 100 tons of white metal.

Refining Blister-Copper.

The elimination of arsenic, antimony and bismuth in the preceding operations has, unless the materials under treatment are uncommonly impure, left only small amounts of these metals in the blister-copper. Their elimination during the refining operation probably takes place entirely by scorification. The products, refined copper and refinery-slag, together contain quantities of arsenic, antimony and bismuth equal to those present in the blister-copper subjected to the operation.

In the tables on p. 663 the products of refining are calculated from the working-results on 100 tons of blister-copper.

Roasting White Metal—Elimination of Arsenic, Antimony and Bismuth.

	Weight Tons.	Arsenic. Per Cent.	Arsenic. Tons.	Per Cent. Relative. Original Arsenic=100.
White metal roasted.......	100.0	0.089	0.089	100.0
Products:				
Blister-copper...............	70.1	0.083	0.058	65.2
Roaster-slag..................	16.3	0.092	0.015	16.8
Total......................	....	....	0.073	82.0
Difference due to volatilization			0.016	18.0

	Weight Tons.	Antimony. Per Cent.	Antimony. Tons.	Per Cent. Relative. Original Antimony=100
White metal roasted.......	100.0	0.039	0.039	100.0
Products:				
Blister-copper...............	70.1	0.024	0.017	43.6
Roaster-slag..................	16.3	0.084	0.014	35.9
Total......................	....	....	0.031	79.5
Difference due to volatilization			0.008	20.5

	Weight Tons.	Bismuth. Per Cent.	Bismuth. Tons.	Per Cent. Relative. Original Bismuth=100.
White metal roasted.......	100.0	0.015	0.015	100.0
Products:				
Blister-copper...............	70.1	0.003	0.002	13.3
Roaster-slag..................	16.3	0.012	0.002	13.3
Total......................	....	....	0.004	26.6
Difference due to volatilization			0.011	73.4

A variation of the usual plan of purifying copper by scorification is described by Dr. E. D. Peters* as follows: "The addition of 3 to 5 per cent. of pure white metal—subsulphide of copper—to the bath at the beginning of the refining operation has a most rapid and satisfactory effect in removing both antimony and arsenic. Very bad cases may require two such additions with an intervening oxidizing operation." This is, in effect, throwing the copper back and enforcing a prolonged

* *Modern Copper-Smelting*, 7th ed., p. 504.

Refining Blister-Copper—Elimination of Arsenic, Antimony and Bismuth.

	Weight Tons.	Arsenic. Per Cent.	Arsenic. Tons.	Per Cent. Relative. Original Arsenic = 100.
Blister-copper................	100.0	0.452	0.452	100.0
Products:				
Refined copper...............	94.4	0.340	0.321	71.0
Refinery-slag.................	12.5	1.142	0.143	31.6
Total......................	....	....	0.464	102.6
Difference due to volatilization			Nil	Nil

	Weight Tons.	Antimony. Per Cent.	Antimony. Tons.	Per Cent. Relative. Original Antimony = 100.
Blister-copper...............	100.0	0.037	0.037	100.0
Products:				
Refined copper...............	94.6	0.022	0.020	59.0
Refinery-slag................	12.5	0.124	0.015	40.5
Total.....................	....	....	0.035	99.5
Difference due to volatilization			Nil	Nil

	Weight Tons.	Bismuth. Per Cent.	Bismuth. Tons.	Per Cent. Relative. Original Bismuth = 100.
Blister-copper................	100.0	0.040	0.040	100.0
Products:				
Refined copper...............	94.6	0.033	0.031	77.5
Refinery-slag................	12.5	0.093	0.011	27.5
Total......................	......	....	0.042	105.0
Difference due to volatilization			Nil	Nil

roasting that, I venture to say, would be more effective without the addition of white metal. In roasting copper, the removal of arsenic and antimony proceeds with notably greater rapidity after the copper has become dry (*i.e.*, when it is saturated with cuprous oxide) than when it still contains appreciable quantities of iron and sulphur.

With unusually large proportions of arsenic in metallic copper subjected to roasting, there is a considerable elimination of

this element by volatilization. Mr. P. C. Gilchrist,* in his paper on "The Basic Process as Applied to Copper Smelting," gives weights and analyses of highly arsenical "metallic bottoms" roasted in a furnace with the usual siliceous bottom and of the copper produced in the operation. These give the following results for the elimination of arsenic (arranged from data on pages 12 and 13 of paper cited):

	Weight Tons.	Arsenic.		Per Cent. Relative. Original Arsenic = 100.
		Per Cent.	Tons.	
Bottoms	28.0	5.09	1.425	100.0
Products:				
Blister-copper	17.25	0.84	.145	10.2
Roaster-slag	15.4	5.00	.770	54.0
Total	......	......	.915	64.2
Difference, volatilized			.510	35.8
Total arsenic eliminated				89.8 per cent.

In comparing the relative elimination by the reverberatory and blast-furnaces, as shown by the foregoing analytical data, it will be seen that in the reverberatory furnace arsenic and antimony are eliminated in considerable proportion by volatilization and in the ore-slags. These slags do not enter again into the smelting routine. In the blast-furnace the only final elimination is by volatilization, the ore-slags being practically free from these elements. Bismuth, in both methods alike, is eliminated only by volatilization.

In both furnaces the slags from the later stages are returned to the smelting circuit, with the effect of rendering the regulus and copper less pure. To obviate this return of impurities, the roaster- and refinery-slags are in some instances treated separately, and not returned to the ordinary smelting-furnaces.

Bessemerizing Copper Regulus.

The process of treating copper regulus in Bessemer converters (which now replaces, to a large extent, roasting to blister-copper) has an effect in eliminating arsenic, antimony

* *Jour. Soc. Chem. Industry*, vol. x., p. 4 (1891).

and bismuth similar to the roasting methods. The following analytical data show the elimination in treating regulus containing 56 per cent. of copper:

Bessemerizing Copper Regulus—Elimination of Arsenic, Antimony and Bismuth.

	Regulus.		Bar Copper.		Elimination per 100 of Copper.	Total Percentage of Elimination.
	Per Cent. Actual.	Per Cent. Relative. Copper=100.	Per Cent. Actual.	Per Cent. Relative. Copper=100.		
Copper........	56.0	100.0	98.0	100.0	....	....
Arsenic......	0.125	0.223	0.084	0.086	0.137	61.4
Antimony...	0.043	0.077	0.022	0.023	0.054	70.1
Bismuth.....	0.023	0.041	0.004	0.004	0.037	90.2

The above data show that in this process bismuth is eliminated more completely than either arsenic or antimony.

Pyritic Smelting.

I have never had an opportunity to examine the products of the operation known as pyritic smelting, in which the calorific effect of the oxidation of iron and sulphur together with externally heated blast were the main sources of heat. I have, however, smelted siliceous iron pyrites mixed with copper pyrites, using considerably less carbonaceous fuel than is usual in blast-furnace practice. The following data were obtained from smelting such ores to which limestone was added as flux, and for which only 8.25 per cent. of coke was added to the charge. Cold-blast was used. The ores were practically free from antimony and bismuth:

	Weight.	Arsenic.	
		Per Cent.	Weight.
Ore..	100 tons.	0.78	0.78 tons.
Regulus	19 "	0.42	0.08 "

There was thus about 90 per cent. of the total arsenic eliminated in the operation. About 80 tons of slag were produced with 100 tons of ore, and this contained 0.53 per cent. arsenic,

or about 0.43 ton. About 54 per cent. of the arsenic was eliminated in the slag. The remaining 36 per cent. would consequently be eliminated by volatilization.

Working under these conditions, with a powerful blast, the top of the charge was always hot, and probably the whole of the volatilization took place at this point before the charge reached the smelting-zone. The action in the upper layer of the charge would correspond to calcination; but, owing to the high temperature, probably a considerable proportion of the arsenic was oxidized to arsenic oxide, which formed fixed arsenates with the iron oxide and entered the slag. The proportion of coke used would not allow the furnace to be entirely oxidizing; but it is possible that, were a smaller proportion of coke used, the elimination of arsenic by scorification would be even greater.

Mr. W. Gowland* has described an interesting method which is still largely used in Japan, and by the use of which considerable elimination of arsenic, antimony and bismuth is effected. As in the very ancient liquation process by which the early German metallurgists desilverized copper, the impure copper is alloyed, or rather mixed, with metallic lead, and the mixture is heated to a temperature below the melting-point of copper. By this means a porous mass of purified copper is obtained with metallic lead and an excrescence known as *shiromé*. The lead is found to carry all the bismuth, and the *shiromé* practically all the arsenic and antimony that was present in the copper. The following analyses of *Ashiwo copper* are given by Mr. Gowland:

	Before liquation. Per cent.	After liquation. Per cent.
Arsenic,	0.26	0.04
Antimony,	0.16	trace.
Bismuth,	0.10	trace.

In 1889 Mr. P. C. Gilchrist patented the use of basic bottoms for copper furnaces, and, in the paper already quoted, gave examples of their practical working with elaborate analytical data which show very considerable reductions in the time required to eliminate arsenic from copper. Although the advantages and economy of the basic process, as described by Mr. Gilchrist,

* *Jour. Soc. Chem. Industry,* vol. xiii., pp. 463–471.

appear to be highly important, this method of working has been abandoned.

The principle involved in the basic process has long been taken advantage of in the treatment of arsenical copper, though it had never been systematically applied until Mr. Gilchrist worked upon it. It has long been the practice in Swansea and elsewhere to add lime and sodium nitrate to the copper during the refining operation, with the view of hastening the removal of arsenic.

It is possible to concentrate the impurities (contained in the copper) in a small amount of the metallic copper, with a relative purification, and this forms the basis of the operation known as "best selecting." I have already published data* bearing on this process. And, in the case of the elements under consideration, I found that only antimony could be concentrated with any degree of perfection. There is a fair concentration of arsenic in the metallic bottoms, but no such concentration is effected in the case of bismuth.

Elimination by Wet Processes of Extraction.

Atmospheric Oxidation Without Burning.

In atmospheric oxidation of cupreous iron pyrites, and subsequent extraction of copper by leaching, as carried on in Portugal and Spain, arsenic and antimony are to some extent dissolved and reprecipitated with the copper. The proportion in which they are separated and precipitated is only a fraction of the amount contained in the ores. But this is so important as to seriously deteriorate the copper precipitate for smelter's use, and to entail excessive expense in smelting and refining the copper.

The contaminating elements, or their sulphides, are probably oxidized with the copper and dissolved by the agency of free sulphuric acid formed by the action of ferric sulphate on cuprous sulphide. The arsenic is present, in less proportion as metallic arsenic or arsenide than as arsenic acid, forming arsenates, and these compounds are deposited to the greatest extent in the later stages of the copper precipitation. This is probably due to the gradual neutralization of the free acid by the metallic iron in the precipitation troughs, and by the acid

* *Proc. Inst. Mech. Eng.*, London, 1895, p. 254.

solution of ferrous sulphate being oxidized to form neutral solutions of ferric salts. In the oxidizing and neutralizing action, antimonates and basic salts of bismuth are probably deposited with the arsenates. The copper precipitated in the troughs, through which the liquors first flow, is less contaminated with arsenic than that in the later troughs,—the arsenic it contains usually being in the metallic state.

	Pyrites.		Precipitate.		Total Percentage of Elimination.
	Per Cent. Actual.	Per Cent. Relative Copper = 100.	Per Cent. Actual.	Per Cent. Relative. Copper = 100.	
Copper...............	2.00	100.0	62.0	100.0	....
Arsenic..............	0.40	20.0	3.5	5.64	71.8
Antimony...........	0.030	1.5	0.08	0.129	91.4
Bismuth.............	0.016	0.8	0.06	0.097	87.9

Burning and Subsequent Washing of Cupreous Iron Pyrites.

This is the process usually adopted in Spain and, to some extent, in Portugal for the extraction of copper from cupreous iron pyrites. In burning, there is a considerable elimination of all three elements, as was explained in the consideration of roasting of copper-ores previous to smelting. The following may be taken as fairly typical of heap-roasting, preparatory to lixiviation, as conducted in Spain:

	Raw Pyrites.		Burnt Pyrites.		Total Percentage of Elimination.
	Per Cent. Actual.	Per Cent. Relative. Copper = 100.	Per Cent. Actual.	Per Cent. Relative. Copper = 100.	
Copper...............	2.45	100	3.26	100	......
Arsenic..............	0.43	17.55	0.133	4.08	76.8
Antimony...........	0.029	1.18	0.030	0.92	22.0
Bismuth.............	0.015	0.61	0.017	0.52	14.8

Arsenious acid is, to a greater or less extent, deposited in the outer layers of the heaps. The sulphurous acid produced in burning the ore, passing with excess of air over the partially burnt pyrites containing ferric oxide, forms sulphuric acid, which is also, to some extent, caught in the colder portions of the heaps. Consequently, the solutions obtained by

washing contain free acid. This probably acts on the residual and dissolves the partially oxidized arsenic, antimony and bismuth. These elements are precipitated in a manner similar to that in which they are deposited, in the precipitating troughs, from solutions obtained by washing raw pyrites after atmospheric oxidation. Although the proportions of arsenic, antimony and bismuth contained in the precipitated copper obtained by this process are notable and important, they are smaller than in the copper obtained in oxidizing pyrites by the direct action of atmospheric air. The considerable proportions of these elements eliminated during the roasting leave smaller proportions to be subjected to the lixiviation-action.

After the exhaustion of the soluble copper, the residue is laid out with smalls, produced in mining and in the handling of the heaps, and is treated in the same way as the raw pyritic heaps. The contaminating elements are extracted and precipitated as in the corresponding treatment of raw pyrites already explained.

Extraction of Copper from Burnt Cupreous Pyrites.—In this process the chloridation of the copper, preparatory to its solution, is accompanied by the chloridation of the three elements under consideration. These chlorides all being volatile at low temperatures are carried off, to a greater or less extent, in the gaseous current from the furnaces, and are largely dissolved in the wash-water and collected, with the condensed acids, in the tower liquors. Their expulsion is not complete. The arsenic in a notable quantity and antimony in a less amount, mainly in combination as arsenates and antimonates, with some bismuth, remain in the calcined ore. In washing with water, these salts, as well as the bismuth that remains in the calcined ore, are dissolved only in minute traces, so that if the copper is precipitated from these solutions it would be practically free from these impurities. The copper, insoluble in water, that is in the calcined ore, is removed by the use of tower liquors, and under the action of this solvent a considerable proportion of the arsenic, antimony and bismuth that remained in the calcined ore is also dissolved. This increases the proportion of these elements that is already present in the tower liquors. In some works the tower liquors are purified before use. The extent to which these elements are volatilized in the calcining operation may be partially indicated by the proportions in which they are

found in the liquors and in the calcined ore, as compared with the burnt ore under treatment. Burnt cupreous pyrites and the calcined ore resulting from roasting it with 15 to 20 per cent. of common salt contained the following proportion of arsenic: Burnt pyrites, 0.145, and the calcined ore, 0.020 per cent.

In the tower liquors, obtained by washing the gases from the furnaces, there was found: Arsenic, 0.0222 gm.; antimony, 0.0005 gm.; and bismuth, 0.0046 gm. per liter.

The proportions of impurities in the copper from the same ore vary greatly according to whether the practice of treating the aqueous and acid separately is followed or not.

The following data are taken from practice in which the two solutions are not kept separate:

	Burnt Ore.		Precipitate.		Total Percentage of Elimination.
	Per Cent. Actual.	Per Cent. Relative. Copper = 100.	Per Cent. Actual.	Per Cent. Relative. Copper = 100.	
Copper...............	4.65	100.00	73.33	100.00	......
Arsenic..............	0.16	3.44	0.974	1.33	61.3
Antimony...........	0 026	0.559	0.008	0.011	98.0
Bismuth.............	0.018	0.388	0.053	0.072	81.4

An "All-Fire" Method for the Assay of Gold and Silver in Blister-Copper.

BY WALTER G. PERKINS, GRAND FORKS, B. C.

(New Haven Meeting, October, 1902.)

As this particular product holds a place by itself, it seems desirable to give a paper dealing especially with it as a corollary to my paper entitled "The Litharge Process of Assaying Copper-Bearing Ores and Products, and the Method of Calculating Charges."*

The process is first to convert the metallic copper into matte by the addition of sulphur, allowing the two elements to combine at the bottom of the crucible when heat is applied. The

* *Trans.*, xxxi., 913.

flux then acts on the sulphides, oxidizing some of the copper which goes into the slag, while the gold and silver are collected in the lead-button reduced by the sulphur. These buttons are combined and scorified twice, for the purpose of concentrating the values and eliminating the remaining copper, thus reducing cupel absorption-loss to a minimum.

Charge for a 20-gm. Crucible.

Sulphur,	800.0	mg.
Cu (approx.),	0.083	A.T.
$Na_2CO_3 + K_2CO_3$ ($\frac{1}{2}$ and $\frac{1}{2}$),	0.5	A.T.
PbO (free from Ag),	8.0	A.T.
SiO_2,	0.5	A.T.
Salt Cover.		

Method of Operation.

Weigh out 0.25 A.T. of copper borings, divide it approximately into 3 equal parts, and place in 20-gm. crucibles; repeat the operation until four sets have been weighed out, thus having twelve crucibles in all for one assay. Weigh 800 mg. of pulverized sulphur into each of these, and mix with the copper; then add one charge of flux, but do not mix the copper and sulphur with the flux, as these two elements should remain at the bottom of the crucible, to form matte when heat is applied. Shake down; fill the remaining portion of the crucible with salt (NaCl), and place in a dull-red muffle. Raise the temperature very gradually for thirty or thirty-five minutes, at the end of which time some salt should remain, not quite molten, in the center of the top of the charge; this will melt and become quite fluid in a few minutes. The temperature should then be raised, so that, in forty-five minutes from charging, the muffle will be of a bright-red color, the charge quiet, and perfectly fused.

The success or failure of this method, especially the silver result, depends upon the proper regulation of the furnace. Therefore, a detailed description of the manipulation, as practiced by the writer, is necessary at this point.

The muffle used is 17 x 19 x 8½ inches, outside dimensions, in which twenty-five crucibles can be placed at a time. Twelve crucibles containing the blister-copper charges should be placed in the front part of the muffle, so that the action can be watched carefully. In the back part of the muffle may be

placed ore-assays, etc., the results of which are not so easily affected by temperature.

The atmosphere in the muffle must be reducing; otherwise, as the charge fuses, the silver seems to come to the surface, and a portion of it is apparently oxidized (or volatilized) and lost in the slag, making the result from 0.4 to 1.0 oz. per ton too low. A muffle that has a good draught through it always has an oxidizing atmosphere when fired with coal; therefore, some artificial means must be resorted to in order to bring about the desired result. The practice here is to plug the holes in the back of the muffle with bone-ash. Then distribute five crucibles (which are about three-fourths full of fine coal and covered with 3-in. scorifiers) amongst the charge, thus: Two in the back row, one in the center and two in the front row of crucibles, closing the front with a tight-fitting door. This will reduce 1 to 2 gm. of Pb from PbO, if a blank charge is run. In case a gas or gasoline furnace is used, the atmospheric conditions would probably be correct without resorting to artificial means.

Pouring, Slags and Buttons.—All conditions being perfect, the charge will pour very fluid. But care must be taken to rotate the crucible quickly, and tap sharply several times, in order to settle any fine shots of lead that may otherwise be held in suspension or adhere to small recesses in the walls or bottom of the crucible.

The slag, on cooling, should be a yellow silicate of lead at the outside of the cone, becoming finely crystalline and deep-green immediately inside the outer skin. If more than merely the skin of the slag shows as a silicate, the heat has been too great; and if the entire slag is crystalline, with large coarse crystals pointing towards the center, the temperature has been too low, and has most probably left some shots of lead in the crucible. The salt on the top of the cone will be of a deep brownish-red, the depth of color lessening when overheated or when the atmosphere of the muffle had an oxidizing effect.

The button from each crucible should weigh about 18 gm., and break clean and bright from the slag. Care must be taken that a film of lead is not left on the slag where the button breaks from it, as a gas-bubble that has a thin covering of lead appears to form at the top of the button, which adheres to the slag.

Scorification.—Each set is now represented by three buttons weighing 18 gm. each. These are now scorified, to eliminate more copper and concentrate the values. The four sets, each representing 0.25 A.T., are manipulated as follows:

Place four 3-in. scorifiers in a hot muffle for ten or fifteen minutes; then, having reduced the temperature in the muffle to about the right heat to open cupellations quickly, place the sets of three each in the four scorifiers; close the door, and the scorifications should open as quickly as cupellations. When properly opened, lower the temperature to a heat that will just permit the operation to be carried on successfully until covered. Raise the temperature until the slag is hot enough to pour freely; decant as much slag as possible without losing any lead; return the scorifiers to the muffle and allow scorification to go on until covered again; close the door to heat up the slag, and then remove the scorifiers and pour. Each resulting button will weigh about 5 or 6 gm., if the temperature has been kept low from the start.

Second Scorification.—Four 2-inch scorifiers are now heated as before. The buttons from the first scorification are broken down and the slags scraped free of any lead-films on to a filter-paper. Each 5-gm. button is made up to 25 gm. with C.P. test-lead. The filter-paper containing the button and test-lead is folded and put into the already hot scorifier. Conduct the operations at as low a temperature as possible, as these buttons will open easier than the first scorification. Raise the temperature when the buttons are nearly covered with slag, pour, cool, and break down again, watching for small amounts of lead on the slag.

These buttons are now ready for cupellation, and represent four assays of 0.25 A.T. each. Carry on this operation to get "feather" PbO on the cupels. This needs careful watching, as the buttons only weigh 5 or 6 gm. Weigh the beads for silver plus gold in 0.25 A.T. Combine two and two, part, and weigh for gold in 0.5 A.T.

SUMMARY.

1. The litharge must be absolutely free from silver, or, at the most, contain only small traces of silver, in order to avoid the

necessity of correcting by difference. The kind used is of Pueblo manufacture.

2. The temperature must be carefully regulated in all operations. Also, have a slightly reducing atmosphere in the crucible operation, otherwise the silver result will be too low.

3. Great care must be exercised in watching for shots and films of lead, especially after the concentration of sets.

4. The cupels should be nicely "feathered," and when cold should be of a very pale greenish-yellow, denoting the almost entire absence of copper. It is possible to get a good result by leaving more copper in the lead-button, thus doing away with the second scorification. It is best, however, to do as directed, placing beyond doubt the question of the absence of copper in the silver-beads.

5. The flux can be mixed in large batches and measured by having a cup made that equals one charge, the formula being:

$Na_2CO_3 + K_2CO_3$ ($\frac{1}{2}$ and $\frac{1}{2}$),	5 lbs.
PbO,	80 lbs.
SiO_2,	5 lbs.

6. The advantages of this method are:

That it gives results in gold equal to the "all-scorification" method, and in silver equal to the combined wet and fire method.

That it does away with the necessity of making separate estimations for gold and silver, thus saving the time and expense of working the combination-method for silver.

That the time taken is less for each estimation than in the all-fire scorification. In practice it takes from five to six hours to do three determinations of gold and silver.

Truck-Support for Furnace-Bottoms.

BY HENRY A. MATHER, NEW YORK CITY.

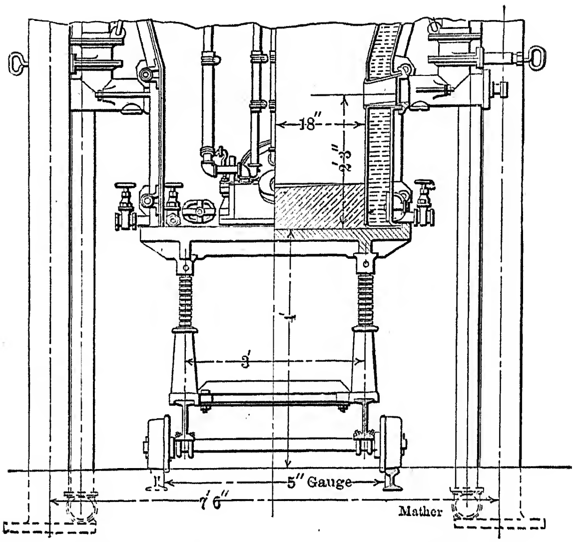
(New York and Philadelphia Meeting, February and May, 1902.)

WHILE this device is not new in its inception, its peculiar advantages failed to be of practical utility until furnace-builders instituted the mechanical reform of supporting the upper and lower water-jackets by hanging them from an I-beam frame, independently upheld by iron columns, instead of resting the entire weight of structure on the bottom, as practice formerly prescribed. The Colorado Iron Works were among the first to build copper-furnaces of this description, and the device, illustrated herewith, has been installed by them in three recent plants,—two furnaces for the Westinghouse interests near Ely, Vermont, and one for the Grand Prize Copper Company, of Gila county, Arizona.

The jack-screw supports (Figs. 1 and 2) and the familiar iron bottom of former practice are retained as integral parts of this new furnace-bottom. And, instead of resting inert on the tap-floor of the furnace-room, the jack-screws are supported on and bolted to two I-beams the length of the furnace, placed immediately beneath, and parallel to, its sides. These I-beams are bolted to, and supported by, three steel axles equipped with small flanged wheels, the whole constituting a carriage, which runs freely on a track. The entire apparatus is movable or rigid at will, for the wheels are easily braced, if the tension of the tightened jack-screws does not serve to hold the whole in position.

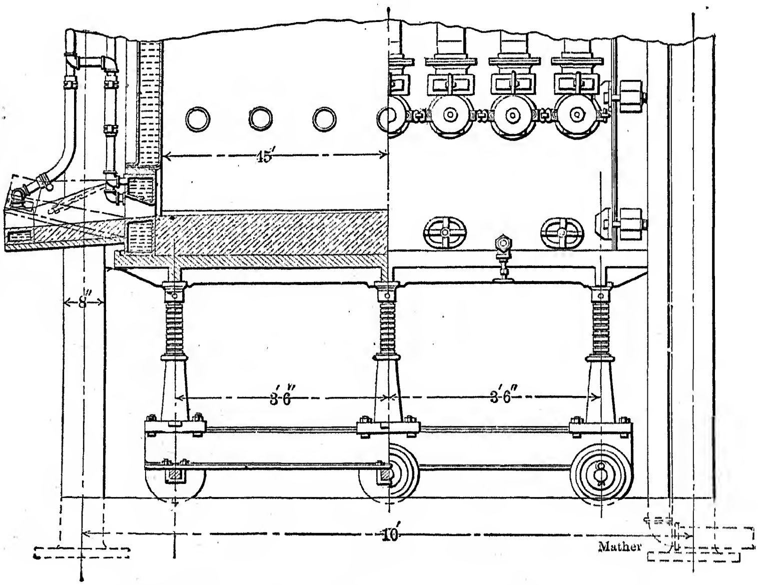
The advantages of this design will be at once apparent to those who have had practical experience in barring furnaces provided with stationary iron bottoms. It is a well-known fact that the larger part of the time occupied in cleaning and preparing a frozen furnace for active service is necessitated by working in a confined place where the temperature is uncomfortable, and that in such case the *débris* must be removed from

FIG. 1.



Cross-section of Furnace Showing Truck-support.

FIG. 2.



Longitudinal Section of Furnace Showing Truck-support.

the bottom of the furnace before the false-bottom of fire-clay, coke-breeze, etc., can be repaired or replaced. Then, too, this superimposed bottom is almost invariably destroyed when the iron plate is pried off the supporting jack-screws, and no renewing is practicable until the plate is once more installed beneath the furnace.

Results from the working of the Grand Prize installation demonstrate that the time lost by "freezing up" is ordinarily reduced over 50 per cent., and with good fortune more economy is possible. The work of barring down and renewing the false-bottom proceeded practically simultaneously. The jack-screws had a play of 10 inches and the false-bottom was built 9 inches in depth, including fire-brick cover.

If the truck-carriage is slowly moved along its track and a hose played into the 1-inch of clearance space thus provided for, the suddenly cooled contents of the furnace (which are commonly untouched by water played from above) crack clear of the brick bottom; and, with the bottom edge of the water-jackets acting as a scraper, very little, if any, of the false-bottom is damaged. The major part of the furnace-contents cling to the material wedged into the space immediately above the bosh, and the removal of the entire *débris* content is rapidly and easily accomplished. The false-bottom, meanwhile, is easily repaired or renewed, and a very considerable saving of time is effected.

The extra cost of this device is not excessive; it is simple in construction and has few or no wearing parts, and it would appear to be a mechanical construction worthy of more general use, especially as there is no patent on either bottom or carriage.

The Copper-Deposits of the Sierra Oscura, New Mexico.

BY H. W. TURNER, SAN FRANCISCO, CALIFORNIA.

(New Haven Meeting, October, 1902.)

LYING to the east of the Rio Grande, in central New Mexico, is a long N. and S. mountain range, broken into separate ridges at several points. These have received separate names; the mountains at the south end, near El Paso, being known as the Franklin mountains, and then, following successively, to the north, the San Andreas range, Sierra Oscura, Manzano and Sandia mountains.

At the eastern base of the Sierra Oscura there are several low ridges, remarkable for their red color. All of these red ridges contain reefs of copper-ore. The eastern flanks of the Sierra Oscura are composed of limestone. Some fossils in the limestone were examined by Prof. J. P. Smith of Stanford University, who says they are *Fusulina* and indicate an Upper Carboniferous age. The sandstones and shales containing the copper-reefs directly overlie this limestone (Fig. 1), and are very likely of Permian age, like the similar beds in Texas, described by Mr. W. F. Cummins.*

Overlying the copper-beds are red sandstones and shales in which very little copper has been found. The cupriferous zone and the red sandstones and shales are everywhere associated, and as one stands on a high point, he will see that these rocks form three main belts or lines of hills. These may be referred to as the northern, middle and southern belts.

The northern belt was not visited by me, but is known to contain copper-deposits.

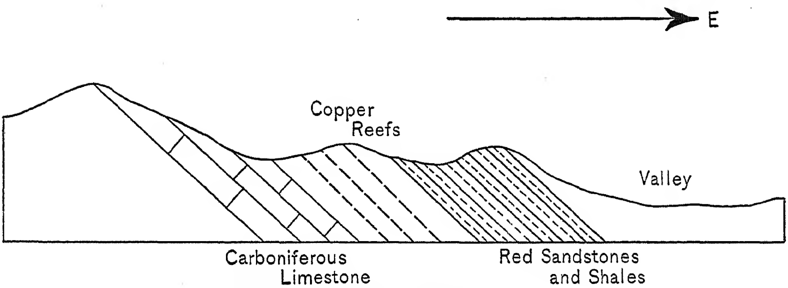
The middle belt has a trend of N. of W. and S. of E. The copper-reefs have been traced for a distance of more than 2 miles.

The southern belt has a trend of about N. 30° W. and S. 30°

* J. F. Kemp, *Ore-Deposits of the U. S. and Canada*, 3d ed., p. 224, and W. F. Cummins, "Report on the Permian of Texas and its Overlying Beds," *First Ann. Rep. Tex. Geol. Sur.*, p. 196.

E. The copper-reefs in this belt have been traced for more than 4 miles. A large part of the north end of the belt is covered by the claims of the Sierra Oscura Co., while the southern portion is covered chiefly by the claims of the Estey Mining and Milling Co. There are at least three distinct reefs in the southern belt which carry copper-ore. These reefs dip with the enclosing sediments, similar to coal-beds, so that they can be followed with great regularity for a long distance. Two of the reefs consist of sandstone containing copper-glance (chalcocite) and copper-carbonate in minute grains disseminated through the rock and in seams. The third reef is composed chiefly of shale, and is 2 to 3 ft. in thickness, the whole of which is impregnated with minute grains of glance and carbonate. The exploitation of the region is still so incomplete that

FIG. 1.



Section through the Sierra Oscura.

no reliable estimate as to amount of ore available for treatment can be made. None of the reefs have been exploited in depth.

Fissure-veins have not been found on the property of the Sierra Oscura Co., but along certain fault-fissures on the claims of the Estey Mining and Milling Co. there are deposits of chalcopyrite.

In addition to the glance, carbonate and chalcopyrite, bornite occurs in the center of nodules which have a diameter of from 1 to 2 in. Such nodules are abundant in shale on the Lucky Jack claim, at the north end of the southern belt. Impressions of leaves may be noted in some of the sandstone, and the copper-ore has in part replaced plant-stems and wood, the texture of which is still preserved.

The more massive sandstone is an arkose, *i.e.*, it is composed of the detritus of granitic rocks. It contains rolled grains of

iron oxide (in part magnetic) up to $\frac{1}{4}$ in. in diameter. This arkose is plainly derived from an underlying granitic area not now exposed, and it is equally clear that this granitic area contained deposits of iron-ore from which the rolled grains were derived. The sandstones rich in iron do not contain any appreciable amount of copper, and the copper-reefs are not rich in iron.

Two partial analyses, made by the El Paso Smelting Co. from car-load lots shipped to them, are given below:

	No. 1.	No. 2.
Silica, per cent.,	65.0	65.5
Gold,	trace.	trace.
Silver, troy oz. per ton,	0.9	1.2
Iron, per cent.,	1.8	5.2
Copper, per cent.,	10.5	9.9

The shipments to the smelter were, of course, of selected ore. The average copper-content of the reefs, as determined from a series of assays made by the Selby Lead and Smelting Co. of San Francisco, is about 4 per cent.

The copper-bearing reefs can best be seen in the southern belt, because more work has been done there. At least two of these reefs, the middle and the lower, are large enough to be worked (being from 1 to 3 ft. in thickness). Future exploitation may show that they exceed this thickness at many points. Certainly one deposit on the Just Before claim, in the middle belt, has a thickness of 7 ft. If the copper-deposits of the Sierra Oscura district were in the form of fissure-veins, no reliable estimate of the quantity of ore could be made without a vast amount of development work; but inasmuch as they are in the form of reefs regularly interbedded in the sandstones, an approximate calculation can be made after the beds have been followed down at a few points. All of the reefs taken together will very likely average 3 ft. in thickness over many miles in horizontal extent.

No dikes or igneous rocks of any kind have thus far been found associated with the copper-reefs or the enclosing beds. They do not occupy lines of faulting; and, indeed, were certainly formed before the main faults of the district, which have caused the copper-bearing sediments to be displaced into the three belts or lines of hills above described. Small faults have caused minor displacements of the reefs at a few points.

The mode of occurrence of the copper-ore in regular beds, in part replacing plant-remains, suggests that, like bog iron-ore, the copper was deposited from the waters which deposited the enclosing sediments.

Commercial Value of the Ore.

The extensive surface-showing has induced considerable prospecting, and a large number of claims have been located. The climate is good, there being rains in July and August to temper the summer heat, and in the winter time the precipitation is small and the temperature not low.

The nearest railroad station is Oscuro, on the El Paso-Rock Island route, about 16 miles to the east, with nearly level land from the station to the mines. There is a store and post-office at Estey City. At Capitan, 35 miles from Oscuro, there are coal-mines containing a good quality of coal, the price of which, delivered at Oscuro in single car-load lots, is $5.50 per ton. There is said to be undeveloped coal near the station, and the Estey Mining and Milling Co. has opened up a 14-in. vein to the south of Estey City. At Alamogordo, on the railroad, 22 miles south of Oscuro, there are two sawmills in active operation, supplying an abundance of cheap lumber.

At Estey City an electrolytic plant has been built for treating 100 tons, or more, of copper-ore per day. Having no recent information regarding this plant, I am unable to state what success it has had.

The decline in the price of copper has made it a difficult problem to reduce the low-grade copper-ore at a profit. The copper-carbonate is not in sufficient amount to be treated by itself by leaching, and the glance-ore would require roasting with pyrite or chemicals before being amenable to a leaching process. It is probably not a good concentrating-ore, as the soft glance would slime. At the time of my visit (1901), no large bodies of pyrite or chalcopyrite were known in the immediate vicinity. The ore could, of course, be reduced in a smelter. Water is available only in wells. The Sierra Oscura is well covered with nut-pine, which makes an excellent fuel.

Under present conditions the Sierra Oscura copper-deposits do not attract the investor, but the large amount of the ore may render its treatment, on an extensive scale, practicable by close business management.

The Effect of Tellurium on Brass.

BY ERWIN S. SPERRY, BRIDGEPORT, CONN.

(New York and Philadelphia Meeting, February and May, 1902.)

THE presence of small amounts of tellurium in certain kinds of copper, and its exceptionally deleterious* influence in producing red-shortness of this metal, led the author to conduct a few experiments on the influence of tellurium on the properties of brass. While these experiments were not intended to be exhaustive, they demonstrate that, as far as the rolling of brass is concerned, tellurium, unless it occurs in far greater amounts than exist in refined copper, cannot be called an injurious impurity. In comparatively large amounts it appears to impart cold-shortness to high-brass.

Tellurium, the rare element that it is considered to be, has recently been extracted on a large scale from the slimes of an American electrolytic copper-works. They have, in attempts to discover some commercial use for it, sent it out promiscuously and gratuitously in quantities which would lead the young chemical student to fancy that a rare element exists only in name. Through the courtesy of Mr. R. L. Whitehead, of Baltimore, the author was able to obtain somewhat over 2 lbs.,† and use it in quantities which, at the market price, would be prohibitive.

In order to add specific quantities of tellurium to brass, a rich alloy of copper and tellurium was previously made. The method was as follows, viz.:

Nine and one-half lbs. of Lake copper were melted under charcoal in a new plumbago crucible, and then $\frac{1}{2}$ pound of tellurium was added in small portions at a time. The mixture was stirred with a plumbago-stirrer and poured into

* See paper by T. Egleston, *Trans.*, x., p. 493. Prof. Egleston was the first to discover that tellurium renders copper red-short.

† At the price quoted by chemical dealers, this quantity is valued at upwards of $1000.

ingots. Considerable heat was generated when the tellurium and copper combined, the metal surrounding the portion of tellurium which was introduced becoming white hot as soon as the combination took place. The cupro-tellurium alloy ran without any film of oxide, and quite freely. The ingots, both hot and cold, broke easily, with a homogeneous and crystalline fracture. This fracture possesses a characteristic brownish-red color.

The copper and tellurium, from which the alloy was made, were carefully weighed on Robervahl balances, and the weight of the ingots of the alloy obtained was exactly 10 lbs. The loss by volatilization or oxidation, then, was too insignificant to be taken into consideration. The composition of this alloy is:

	Per cent.
Copper, ...	95
Tellurium, ...	5

As a standard brass alloy to be used for the experiments, a mixture consisting of 60 per cent. copper and 40 per cent. zinc was used. This alloy, as previously stated,* was employed because it is practically the only high-brass alloy which will work both hot and cold.

The copper was melted in a plumbago crucible under charcoal. The cupro-tellurium alloy was next added, the mixture stirred, and lastly the zinc added. Care was used to obtain the purest copper and zinc. The temperature was kept as low as possible, to guard against excessive loss of zinc. The mixture was poured in an iron mold of internal dimensions of $\frac{5}{8}$ x $2\frac{3}{8}$ x 24 in. The mold was warmed and coated with sperm oil.

Experiment No. 1.—Four lbs. of Lake copper and 2 lbs. of the 5-per-cent. cupro-tellurium alloy were melted together. Then 4 lbs. of Bertha zinc were added. The composition of this alloy is:

	Per cent.
Copper, ...	59
Zinc, ...	40
Tellurium, ...	1

The metal ran into the mold like any high-brass mixture, and, as far as outside appearance was concerned, the plate could not

* *Trans.*, xxvii., p. 485.

be told from ordinary brass. The presence of the tellurium was not superficially disclosed. This plate was rolled cold from a thickness of 0.605 in. to 0.430 in., when it cracked to pieces. The fractures showed large patches of segregated matter. The parent metal, however, was free from crystallization, and possessed a peculiar light-rose color. An ingot having the dimensions of $\frac{3}{4}$ x 1 x 12 in. was forged at a cherry-red heat. When flattened it showed no cracks, but when bent over upon itself a few appeared at the bend. The alloy was quite soft while hot, which indicates that tellurium does not harden the brass appreciably. As the cold fracture of this ingot disclosed no crystalline structure, the cause of the cracking of the plate during the rolling was undoubtedly the segregation.

Experiment No. 2.—Five lbs. of Lake copper and 1 lb. of the 5-per-cent. cupro-tellurium alloy were melted and 4 lbs. of Bertha zinc added. The composition is:

	Per cent.
Copper,	59.50
Zinc,	40.00
Tellurium,	.50

The plate was rolled from a thickness of 0.606 in. to 0.427 in., and cracks appeared upon the edges. It was then annealed and rolled to a thickness of 0.317 in., and the plate cracked to pieces. An ingot of this mixture forged as well at a cherry-red heat as pure brass of the same composition. Even when bent over upon itself and flattened, no sign of cracking at the bend appeared. The cold fracture still has the rose-red tinge and is not crystallized.

Experiment No. 3.—Five and one-half lbs. of Lake copper and $\frac{1}{2}$ lb. of the 5-per-cent. cupro-tellurium alloy were melted and 4 lbs. of Bertha zinc added. This gives the following composition:

	Per cent.
Copper,	59.75
Zinc,	40.00
Tellurium,	.25

The plate was rolled from a thickness of 0.605 in. to 0.425 in., and a slight cracking took place at the edges. It was then annealed and rolled to a thickness of 0.295 in., and the edge-cracks increased in size slightly. The plate was annealed a second time and rolled to 0.112 in., and the sheet split in many

places, so that further rolling was useless. Perhaps this sheet, by careful working and frequent annealing, might have been rolled to a much thinner gauge; but as pure brass stands these reductions, it is evident that this percentage of tellurium appreciably affects the working-qualities of the brass.

In the hot-forging, this alloy revealed no sign of hot-shortness, and in its behavior was identical with the previous mixture.

Experiment No. 4.—Five lbs. of Lake copper and 1 lb. of an alloy of tellurium and copper containing 1 per cent. of tellurium (made by reducing the 5-per-cent. alloy with copper) were melted and 4 lbs. of Bertha zinc added. The composition is:

	Per cent.
Copper,	59.90
Zinc,	40.00
Tellurium,	.10

The plate was cold-rolled from a thickness of 0.600 in. to 0.403 in., and no cracks appeared. It was annealed and rolled to 0.273 in., and cracked badly on the edges. This plate was annealed a second time and rolled to 0.050 in., and while the edge-cracks increased in size, the sheet rolled as well as a plate of poor brass would under similar conditions. This amount of tellurium appears to be the dividing-line between the quantity which can be allowed in good brass and that which will cause cracks in rolling.

In forging, this alloy behaved like pure brass of the same proportions.

Experiment No. 5.—Five and one-half lbs. of Lake copper and ½ lb. of the cupro-tellurium containing 1 per cent. of tellurium were melted and 4 lbs. of Bertha zinc added, which gave the following composition:

	Per cent.
Copper,	59.95
Zinc,	40.00
Tellurium,	.05

The plate was cold-rolled from a thickness of 0.611 in. to 0.405 in. No cracks appeared. It was annealed only once, and rolled to a thickness of 0.050 in. When 0.120 in. was reached, however, the sheet began to crack on the edges, but only in

the same degree that pure brass would under like conditions. As far as could be seen, this alloy rolled equally as well as brass free from the tellurium. No cracks appeared in forging, even when bent and flattened at the bend, which indicates that this percentage of tellurium has no effect on the hot-working qualities of high-brass.

The results of these experiments show that the amount of tellurium usually contained in refined copper does not appreciably affect the rolling properties of high-brass. If, however, the copper contains over 0.10 per cent. (giving about 0.06 per cent. in the brass), the metal manifests a tendency to crack in the rolling.

The hot-working qualities of high-brass, paradoxical as it may seem, do not appear to be much affected by the presence of tellurium; a marked contrast to that of copper in which the presence of a few thousandths of one per cent. renders the metal appreciably red-short.

Basaltic Zones as Guides to Ore-Deposits in the Cripple Creek District, Colorado.

BY E. A. STEVENS,* VICTOR, COLO.

(New York and Philadelphia Meeting, February and May, 1902.)

It has been ascertained in recent years that certain rock-types, geological formations and structural conditions may be used as fairly reliable guides, when prospecting in recognized mineral belts or mining districts, with a reasonable certainty of discovering "pay-ore;" and that such is considered as a practically established conclusion may be inferred from a perusal of the recent reports of the U. S. Geological Survey and the literature of the several scientific societies discussing mining, geology, and kindred subjects.

Cripple Creek is no exception to this conclusion, and the

* Died January 31, 1902. The manuscript of this paper was received only a few days before his untimely death, the formal notice of which will appear in the next annual report of the Council.

rock-type or association, rather than the structural condition, is the most infallible guide.*

These guides consist of four, possibly five, dike-rocks, three of which are extremely basic, while the fourth is an acid rock of an entirely dissimilar character. The basic rocks are nepheline-basalt, limburgite, feldspar-basalt and tephrite. There are grounds, however, for believing that the two latter are subdivisions of one type, and therefore will be described under one head. The acid rock is quartz-porphyry.

Nepheline-basalt is a rock encountered in but few localities elsewhere on this continent, and occurs in narrow dikes cutting various formations. When typical,† it is composed of nepheline, augite and olivine, with hornblende, mica, and, rarely, plagioclase, as accessories. In this district, however, it may contain all of the above, with the addition of magnetite.

Limburgite, which was positively identified in this district quite recently, is a rock closely allied to nepheline-basalt, both structurally and chemically. It is composed of a glassy ground-mass, containing large and small augites, magnetite, abundant megascopic olivines, and some mica, shading locally into a variety, verite. It also here contains the rare accessories, plagioclase and, occasionally, nepheline.

The last of the basic rocks, usually referred to as feldspar-basalt, is probably tephrite,‡ as nepheline, which is present microscopically, is too abundant locally to be considered as other than an essential constituent. This rock is composed of plagioclase, augite, and some nepheline. The accessories here are biotite, magnetite, apatite, titanite, an undetermined mineral which is probably sanidine, and, rarely, olivine.

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* The writer will not deny that in a very few instances there is apparently a relation existing between a late, extremely basic andesite and ore-deposition, but is very confident that sufficient development will demonstrate, as in similar cases heretofore, that these deposits are more closely allied to basaltic dikes or zones.

† The nepheline-basalt of this district is not a typical rock; for instance, the dike extending northward from Battle mountain, along the east side of Arequa gulch, contains glass, much megascopic biotite and plagioclase, and is remarkably poor in nepheline. This condition confirms the opinion of the writer, expressed in a previous paper (*Trans.*, xxx., 763), that much of the so-called nepheline-basalt is limburgite.

‡ No nepheline is present in the dike of the Seavey shaft on Block 7 of State land; but in the same dike, where exposed by the 40-ft. shaft of the "Little Daisy" mine, the higher power of the microscope reveals many crystals in each slide.

The one dike of quartz-porphyry, with its few branches, is unique in its occurrence. It was casually referred to by Dr. Cross in Part II., Sixteenth Annual Report, U. S. Geological Survey, and has otherwise escaped observation. (See Fig. 4.) It has a very compact, bluish-black ground-mass, composed of orthoclase, much plagioclase, quartz, and some augite or other dark silicate. The structure is distinctly tabular-jointed. Scattered through the ground-mass are a few double-terminated, greasy quartz-crystals, and an occasional phenocryst of orthoclase or sanidine. Physiographically, it, like the tephrite, resembles the nepheline-basalt and limburgite. These rocks, as dikes, comprise the later intrusions; nepheline-basalt and limburgite were contemporaneous, and probably the last extruded.

These dikes cut all the earlier formations of the district. The latter, with the exception of granite, schist and diabase, are generally classed, by the miners, as "porphyry;" they really consist of andesitic and phonolitic tuff and breccia, massive and dike andesite, phonolite, trachytic-phonolite, nepheline-syenite, and, in two instances, trachyte. Owing to the early decomposition of the basalt and limburgite upon exposure to the atmosphere, these dikes, with one exception of limburgite, form no outcrops; nor have they, except on very rare occasions, been found in a sufficiently fresh condition for determination. The same is also true of the tephrite. The two former, when fresh, are very compact, of a greenish-black color, showing only phenocrysts of olivine, except the verite, which contains many crystals of biotite an inch or more in diameter. The tephrite exhibits a compact ground-mass, containing megascopic phenocrysts of augite and plagioclase.

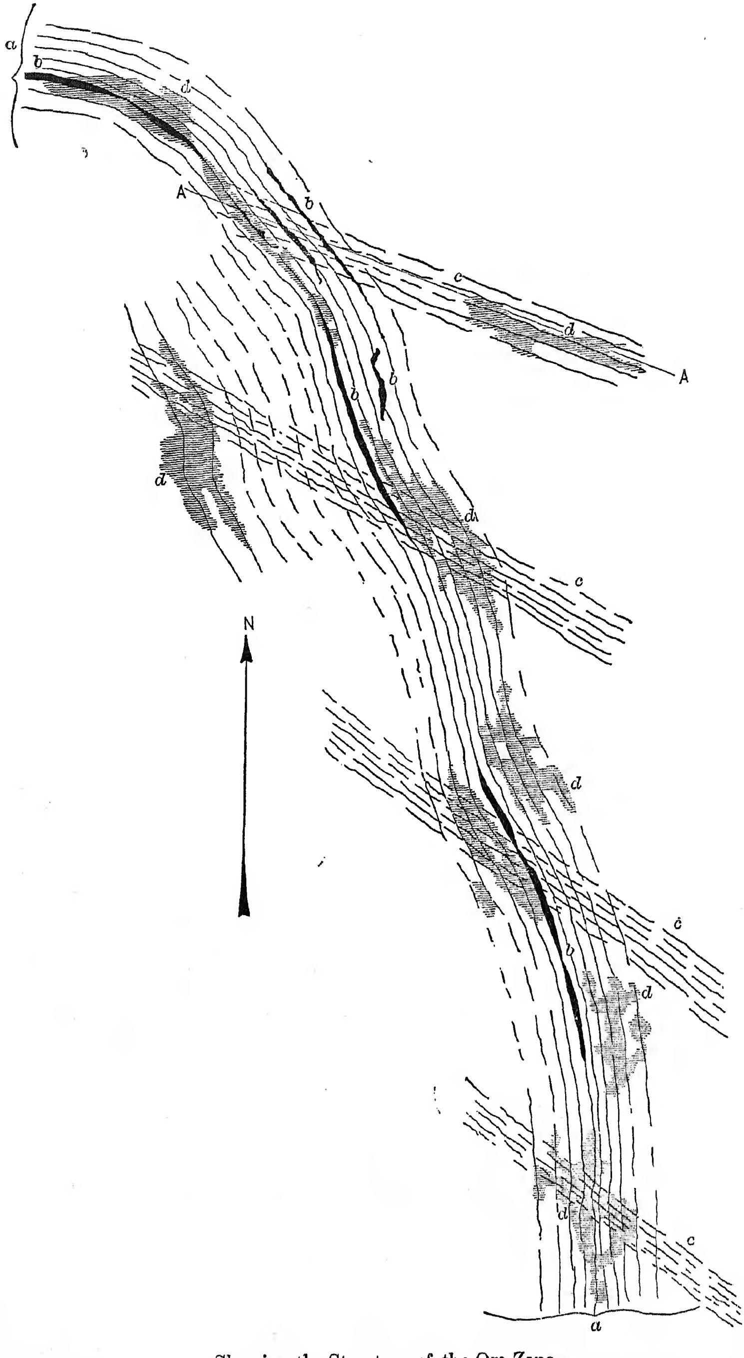
The structure of each basaltic rock, when fresh, is jointed, and the fracture, when broken transversely between joints, is conchoidal. The first stage of decomposition is a zeolitization along the joint-planes, which is soon followed by devitrification, and, subsequently, a breaking down of the entire mass, finally resulting in serpentine.

The practical importance of the presence of these rocks cannot be overestimated. It is not intended to convey the idea that at every point at which one of these dike-rocks may be exposed, ore is, or will be, found in paying quantities. It is a

well-established fact that the ore occurs at varying intervals along the veins in the form of "shoots" or "chimneys," often separated by thousands of feet of barren vein-matter. The assertion is sometimes made that there is not a profitable mine in the district that does not show either the presence of one or more of these dike-rocks or a certain direct relation existing between them and the ore. This relation may be explained thus: The fissures to which the dikes belong are approximately parallel and occur in systems, and one or more of the fissures may contain the dike or dikes, which are very erratic; and it has frequently been observed that the dike-bearing fissures may be devoid of filling for hundreds of feet in depth and thousands of feet in length. These fissured zones often, although not always, extend entirely across the district,* and are from 100 to 1200 ft. wide. The zone comprises hundreds of fissures (many of which are often detected only by the aid of a powerful microscope), separated at times by microscopic bands, and at others by many feet, of country-rock. The veins and their ore-deposits may occur either in the dike-bearing fissure, including the dike, or any other fissure or fissures of the zone. (See Fig. 1.)

It may be inferred from an examination of this figure that the ore-deposits should be more properly assigned to the cross-veins, as the greater number of the "shoots" or "chimneys" occur at the points where these intersect the main veins. This condition will be briefly explained for the benefit of those who are not familiar with the local characteristics of ore-deposits. It will be readily understood that at these points of intersection the channels for water would be more open, and the solutions containing the minerals would meet with much less obstruction to circulation than if there was but one system of fissures or fractures, and would, consequently, spread over areas and follow lines of least resistance. Comparatively

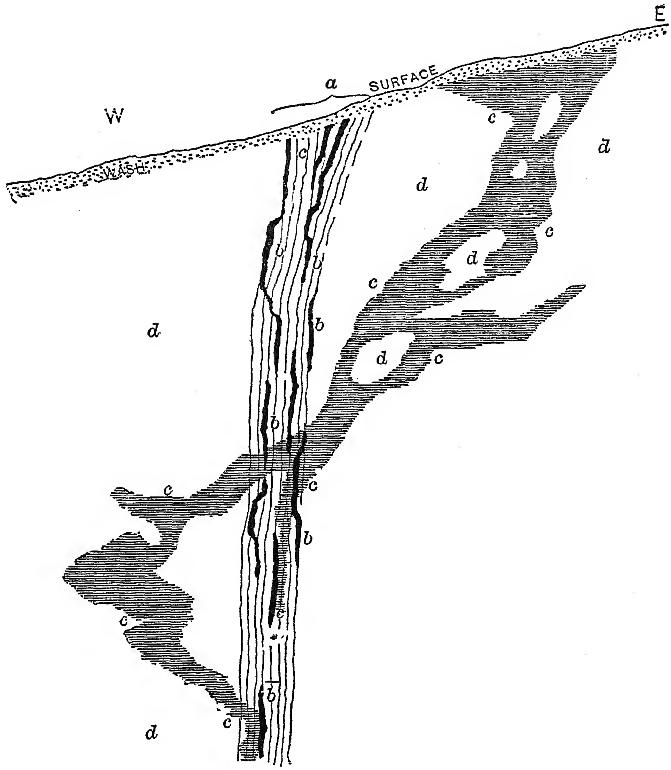
* The Beacon hill mines are on a direct line with some of the limburgite dikes that cut Gold hill in a northerly and southerly direction, and are unquestionably on the same zones. The writer has traced one fissure, which contains the western branch of the basaltic mass at the Dolly Varden mine, southward through Raven, Guyot and Beacon hills, and has observed ore along it at no less than ten different points. A like condition prevails regarding the position of the mines on the north slope of Bull and the east slope of Ironclad hills, with reference to the basaltic zones to the southward.



Showing the Structure of the Ore-Zone.
a, Fissured zone. *b*, Basalt. *c*, Ore-shoots. *d*, Cross-fissures.

speaking, our studies and observations are but superficial, and we may not judge of the conditions farther down in the earth (where is presumed to be the ultimate source or turning-point of the mineral-bearing solutions); we can observe them only as they approach the surface. There are instances where veins crossing the main fractures at a high angle contain the only known shoots, which reach the surface hundreds of feet away

Fig. 2.



Section on line A A, Fig. 1.
a, Fissured zone. *b*, Basalt. *c*, Ore-shoots. *d*, Cross-fissures.

from the points of intersection. But in sinking upon or developing these "shoots" in depth, it is found that they gradually, though persistently, approach the point of crossing with the main system in their downward course; and in many instances they have been found to pass through the intersection, return to it, and then follow the main system to as great a depth as developed. (See Fig. 2.)

These are the zones, therefore, that must be discovered before permanent mines can be opened up; but, as usual, the difficulty lies in distinguishing those which are likely to prove productive.

Dikes of considerable thickness maintain their individuality through the various stages of decomposition and alteration, independent of their environment, while the very thin dikes pass into the hydrous silicates of magnesium or aluminum, forming the ordinary so-called "talc" of our veins,—under which condition, from a practical standpoint, identification becomes impossible. Another obstacle to the determination is the extreme secondary silicification to which not only the dikes themselves, but the entire area of eruptive rocks have been subjected.* Moreover, it is not always possible, with limited development, to determine to what extent the intrusions may be apophyses, which many of the so-called dikes of these basaltic rocks have proven to be. Under such conditions the accompanying ore-deposits, if any, correspond in amount to the dike-matter, as will be instanced later on. This district has been subjected to many disturbances, both orogenic and volcanic, as is indicated by the many faults, fractures and displacements in and surrounding the locality, and the variety of ejectamenta thrown out by the volcano. The disturbances may have been confined to one period, but that period must have been divided by long intervals of time.

Each movement had its own system of fissures, often intersecting the preceding system at a low angle, and its distinct type of lava to fill those fissures.

It is proper at this time to state that the pre-Tertiary fissures, most noticeable in the southern portion of the district, have no observable connection with the Cripple Creek volcano, and, when filled with dike-rock, the filling is of diabase.

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* It has recently been stated that the proximity of the veins, while conducting exploration-work in this district, may be recognized by an increased silicification, which reaches its maximum at and through the veins. A very casual examination of the surface of this region will suggest the untenability of this position. The veins of this district have eroded away proportionately to the enclosing breccia and granite; no more nor no less. If they were silicified to an extreme or even an unusual degree, comparatively, they would form sharply-defined ridges against the breccia or granite background; while, if silicified to a less degree, gulches, hollows or depressions would mark their apices.

For reasons which have already been given, it is known that the rocks referred to as guides represent the latest lava extruded by the volcano.

It is also positively known that ore-deposition occurred subsequent to the latest eruption or intrusions, as mineralization has occurred through and along the latest dikes where they are intersected, crossed or followed by the fissures which form the veins. And it is a significant fact that these later fissures, while occurring almost independently of the dikes, seem to belong to the same general fissured zones, and doubtless represent shrinkage-cracks, probably along lines of weakness resulting from the contraction of the mass upon cooling, immediately following the intrusion of the dikes. These cracks were further enlarged, individualized and intensified by faulting-movements, which unquestionably are responsible for transportation, localization, and probably, to some extent, deposition of the ore.

It has been argued by some that the later dikes cut the veins, and that at the points of intersection for the full width of the dikes no ore could be found. This opinion, it is believed, is formed from a lack of careful investigation and study, and an improper appreciation of circumstances and surroundings. Existing conditions do not warrant such a belief or confirm such an opinion.

The most prominent instance upon which this argument is based has been thoroughly investigated by the writer, physiographically, chemically and microscopically. It was thereby positively determined that the rock in question is not a Tertiary basalt, but an ancient diabase. Several years ago (owing to its extreme decomposition and alteration and the position which it occupies, being near the contact between the breccia and granite) it was mistaken for andesite. It is also inferred, from such investigation, that the rock was so highly altered long prior to the circulation of the ore-bearing solutions that none of the necessary reagents for precipitation had been retained; nor could it, in its condition, maintain the temperature presumed to be necessarily attendant upon ore-deposition.

It is not to be expected that the fissures would maintain their individuality through a decomposed, crumbling formation, although considerable silicification might characterize the mass locally.

It has further been urged, in support of this theory, that the deposits, admitting that such occur, through and along dikes, are "secondary enrichments" from decomposition and leaching of the ores from the lateral points where the veins have been cut off by, and adjoin, the dikes; but no explanation is offered by its exponents as to why the fissures extend uninterruptedly through the dikes, where in a sufficiently preserved condition to support them.

The latter argument is not logical, as the deposits occurring in the dikes are composed of sulphides and tellurides, corresponding in every particular with the veins before entering or crossing them. And even if these fissures and veins, containing ores consisting of the original minerals, did not extend through the dikes, the explanation would be that the dikes were still in a plastic state when the fissures were formed, all evidence of which would then become obliterated when the lava solidified. There are instances, to be sure, where the original gold-bearing minerals to be seen in the dikes have become much more oxidized than in the enclosing country-rock; but this condition should be expected in all basic rocks, owing to their many easily-destructible constituents. In the quartz-porphyry, however, the sulphides and tellurides show the effects of oxidation much less than in the enclosing breccia and phonolite, although this dike is characterized by both augite or pyroxene and plagioclase.

The following mines, with which the writer is familiar, having been connected with them professionally or otherwise, will be cited as examples in support of the arguments advanced in this paper:

1. In various "workings" of the Portland, Independence, Strong, Dillon, Monument and Granite mines, upon Battle mountain, there is a zone containing several distinct nepheline-basalt dikes, all having a general northerly and southerly course, and many short, lenticular* masses or "plugs" of the same basalt, often wholly altered or heavily mineralized, forming locally good ore. This zone is about 1200 ft. wide.

2. The May Belle Tunnel, Gold Coin, Ajax, Dead Pine, Triumph, Coriolanus and Carbonate Queen mines, upon the

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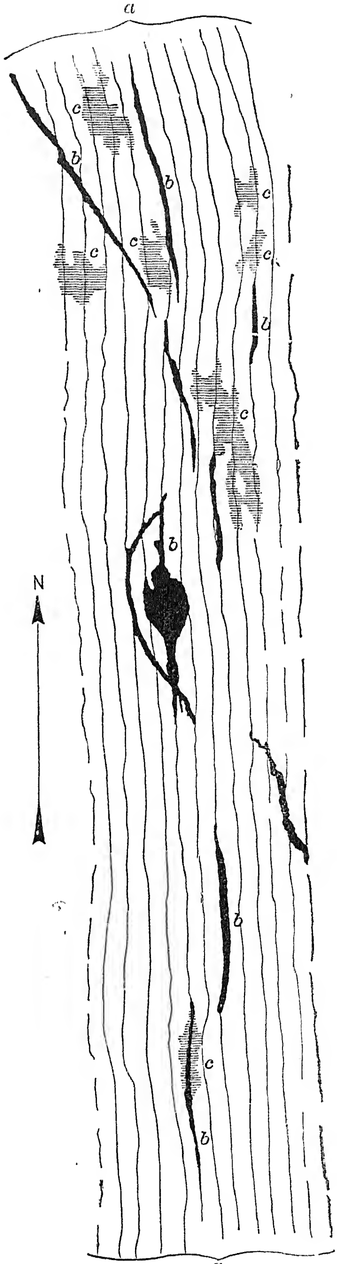
* Inclination with dip of veins, in all cases herein cited.

same mountain, are penetrated or crossed by dikes of limburgite, or the fissured zone to which the dikes belong. This zone is about 600 ft. wide, and a broken, erratic dike of limburgite extends along it, having a N. and S. course. Near the southern extremity of the zone one of the fissures is filled with verite for a distance of several hundred feet. Near the center of the zone, transversely, occurs a small vent or crater, filled with limburgite. (See Fig. 3.) The dike splits near the Ajax mine, the branches separating, and the principal one veers slightly to the northwestward, passing through Eclipse ground near Arequa gulch, and into the Moose mine on Raven hill.

3. The Thompson, Elkton, Raven and Tornado mines, located upon Raven hill, have their workings in and along nepheline-basalt dikes, the entire thickness of which, at times, comprises the ore-bodies.

4. The Pointer, Midget, National and Moon-Anchor mines, all upon Gold Hill, save the National, are situated upon a narrow-fissured zone, having a NNE. course. One strong dike of limburgite which enters them is traceable for a half-mile through the granite to the southward. Near the contact (between the granite and breccia) the dike is scattered by a quartz-porphyry dike, which it then follows. A few hundred feet to the northeast of this point it again becomes well-defined and passes to the northward.

Fig. 3.



Showing the Relation between Limburgite and the Ore-Zone.
a, Fissured zone. *b*, Limburgite.
c, Ore-shoots.

In the northern portion of this zone occur several parallel dikes of limburgite.

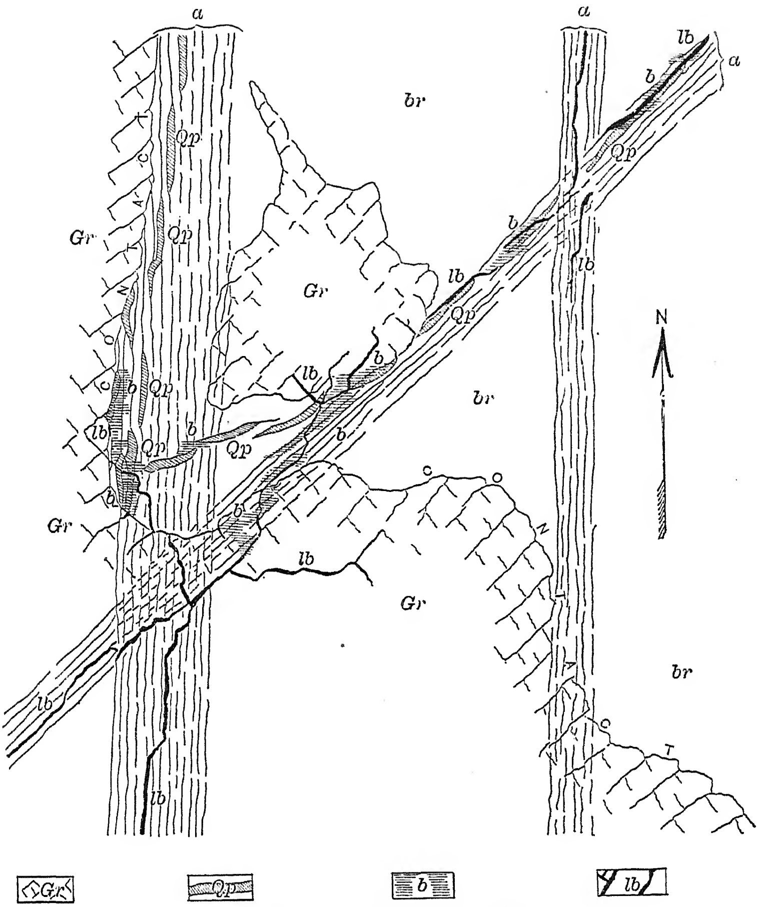
It has very recently been discovered by the writer that the ore-deposit worked through the National mine is associated with one of the late igneous eruptives. This mine is located on a narrow easterly and westerly fissure-system in the granite, some 500 feet west of the westernmost fissure of the north-south zone. The condition of the few lens-shaped masses of basaltic rock (which is limburgite), conforming to the fissure-cavities, stamps this occurrence as an apophysis. This supposition is also borne out by the fact that the ore-body was very limited.

5. The Red Spruce, Accident, Mint, Union Belle, Hillside, Moonlight and Anchoria-Leland mines, on Gold Hill, are penetrated by, or have their ore-bodies composed of, or associated with, quartz-porphyry and limburgite.* The quartz-porphyry dike occupies one or more fissures of a zone having a course approximately northeast. This dike is much brecciated, and not as well defined as the basaltic dikes. It was contemporaneous with a movement of the country which had not entirely subsided until the dike had cooled; therefore, its continuity is broken in many places between the contact, where it has its westerly termination, and the point where it is intersected by the limburgite, described in case 4. A portion of the limburgite deviates from its regular course at this point, and subordinate amounts are observed at various intervals accompanying the quartz-porphyry as far as explored. This is the narrowest zone of the several described, not exceeding 100 feet in width at any point.

The Red Spruce and Accident mines, in this connection, deserve especial mention, as they differ considerably from any other mines in the district. They are both situated on the

* The dike of limburgite following the NE.-SW. fissured zone, represented as coming in at the southwest corner of Fig. 4, reaches across, diagonally, from another N.-S. fissured zone to the west. It does not cross the westernmost zone, however, but turns southward and follows it for some distance before "pinching." This N.-S. zone passes through the Gold Bond property, the El Reno mine,—famous for having produced the first calaverite-bearing ore of the district, —and its influence is next observed in the Dead Shot and Mary Nevin properties to the southward.

FIG. 4.



Limburgite Dike in El Reno Mine.
br, Breccia. *Gr*, Granite. *Qp*, Quartz-porphyry. *b*, Ore-shoots. *lb*, Limburgite.

true contact* between the breccia and granite. There are small, detached bodies of phonolite, trachyte, limburgite and quartz-porphyry present in their workings. The first two are

* A line drawn from the northeast shoulder of the contact, near the center of Fig. 4, northwestward, along the easterly side of the detached granite mass, would represent the position of the contact as described in all literature and shown on all maps of the district so far published. This is for the reason that all of the maps are copies, with a few omissions or additions, of the "Special Cripple Creek Sheet" issued by the U. S. Geological Survey. Dr. Cross, who was in charge of the field-work of the Survey, attempted to represent approximately, only, the position of the contact at this and other points.

of limited, the third of general, and the last of special, economic importance. The limburgite which appears in the Accident shaft at a depth of 240 feet crosses the contact at an approximately right angle, piercing the granite to the westward. This is an apophysis, and its individual influence is not remarkable. The quartz-porphyry follows the contact, at times, then deviates to the westward, into the breccia, following fissures parallel to the contact for 50 or more feet, and then again breaks across the formation to the contact. A branch of this dike extends northward under conditions as described, while the main dike passes to the northeast into the Mint, Union Belle and Hillside mines. The chief ore-bodies of the Accident and Red Spruce mines contain lead, silver and gray copper* (all characteristic of quartz-porphyry), some gold-bearing pyrite, also calaverite and sylvanite.

6. The Zenobia, Pharmacist, Burns, Orphan Belle, Isabella, Block 8 of State land, Free Coinage, Lucky Guss, Deadwood, Delmonico, Vindicator, Christmas and Golden Cycle mines, situated upon Bull Hill, are crossed by or associated with tephrite or feldspar-basalt.

7. An examination of the Victor mine disclosed lenticular masses of a basaltic rock accompanying the vein, too highly mineralized for accurate classification.

8. The same condition was observed in the Doctor-Jack Pot workings on Raven Hill; and much of the breccia, heretofore classed as "andesitic," contains fragments of basalt or limburgite.

It will be observed, therefore, that the mines which have produced 90 per cent. of the gold of this district, which has amounted to more than $115,000,000 during the past ten years, are penetrated or crossed by, or closely associated with, the various basaltic rocks and the dike of quartz-porphyry; and for these very important reasons I infer, and it appears to be both logical and proper to state, that the rock-types and association above described are the true and only guides to point out the probable course to pursue in order to open a "pay mine" in the Cripple Creek district.

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* The superintendent of the Accident mine informs me that he found a "kidney" of gray copper-ore in a "split" in the dike (quartz-porphyry), containing about 1000 pounds, which sampled 5000 ounces silver and 50 ounces gold per ton.

Igneous Rocks and Circulating Waters as Factors in Ore-Deposition.

BY J. F. KEMP, NEW YORK CITY.

(New Haven Meeting, October, 1902.)

IN submitting an additional contribution to the discussion on ore-deposits in the recent volumes of the *Transactions*, it is my desire to adhere closely to matters of material importance as affecting the actual processes. Judging from the discussion by Professor Van Hise, and from one or two reviews or other articles by associates of his in geological work, the impression seems to prevail that, in so far as my paper* referred to his masterly essay,† I was guilty of misconceptions regarding both the part attributed by him in it to the igneous rocks and the ubiquitous presence of the ground-water. I should regret extremely to be wanting in these particulars or to have misunderstood one for whose great services in this and other branches of geology no one has a higher esteem than myself. I have, however, in the most careful way, and with these points in mind, read his essay again, and, taking it as a whole, I cannot gain any different impression of relative magnitudes than the one first received. The importance of the igneous phenomena and the restrictive influence of the processes described by "cementation" in their effect upon the ground-water, as set forth in Professor Van Hise's "Discussion" (*Trans.*, xxxi., 292), impress me as being in very marked contrast with the same things in his first essay. If the point seems to anyone of sufficient importance, it can easily be decided by reading the originals. My paper was the result of some years of observation, reading and reflection, and was meant to be an independent contribution, controversial only in some subordinate particulars. In depicting the drama of the deposition of ores, I cannot but feel that Professor Van Hise assigned to the chorus and the scene-shifters some characters which, it seems to me, should

* "The Rôle of the Igneous Rocks in the Formation of Veins," by J. F. Kemp, *Trans.*, xxxi., 169, and *Genesis of Ore-Deposits*, p. 681.

† "Some Principles Controlling the Deposition of Ores," by C. R. Van Hise, *Trans.*, xxx., 27, and *Genesis of Ore-Deposits*, p. 282.

have been among the leading parts. This is not to imply that the chorus or the supernumeraries are unimportant or unessential members of the cast. On the contrary, no presentation could be given without them; and the earnest student of the text of dramas will quite invariably find them mentioned in the inconspicuous way appropriate to their modest station.

Still, psychology on the surface of the earth does not materially affect the production of veins in the depths; and, with this preliminary clearing of the ground, points of more consequence may be taken up. All veins and replacements, and the greater number of contact-deposits, must have been produced through the agency of underground water aided by auxiliary reagents and heat. No sensible man can doubt this. Unquestionably, moreover, where there is a continuous column of water possessing "head" and operating through sufficiently open channels, circulation will ensue. The underground water and related solvents must be derived either (A) from the emissions of eruptive rocks or (B) from meteoric sources, possibly during sedimentation. When the latter, the heat which is essential to promote circulation must come (1B) from the crushing and frictional rubbing of particles or similar dynamic causes in rocks, or from chemical reactions; (2B) from the normal increase of temperature with depth; or (3B) from igneous intrusions. (Compare "Principles, etc.," *Trans.*, xxx., 49. Much the same appears in the writer's "Ore-Deposits of the U. S. and Canada," 3d ed., pp. 26 and 27, 1901.) The discussion of these several topics will, I believe, cover the debatable points.

A. Emissions of eruptive rocks. This point has been discussed briefly in the first part of my former paper, and I am led to believe that it deserves all the importance which is there given it. A citation from the *Zeitschrift für praktische Geologie* for October, 1901, p. 383, bears on this point. The original in the "Echo" is inaccessible to me.

"The gases which are emitted by the plutonic rocks, when the latter are strongly heated, present a subject of notable interest in so far as it is necessary to believe that a part of them were enclosed in the rocks at great pressure at the time of consolidation. According to the 'Echo,' Armand Gautier has submitted to strong ignition a number of rocks which had crystallized at high temperatures and pressures. From each 100 volumes of the following varieties he obtained at

a red heat the stated volumes of gases: granite, 670; ophite, 760; porphyry, 740. Since we must believe that these rocks, while beneath the surface, were often heated to similar temperatures, which are below those prevailing at their time of consolidation, it is clear that the results possess an important bearing upon the question of the production of the volcanic gases and of those dissolved in hot-springs. If we give due weight to the expansive power which these rock-gases must develop whenever the pressure upon the heated rock in the interior of the earth permits, we see that the old theory of the production of volcanic outbreaks by the introduction of water is no longer necessary. By a still stronger ignition the volume of the emitted gases appreciably increases. At 1000 degrees (centigrade) granite affords, according to the calculation, 20 times its own volume of various gases, besides 89 times its volume of steam; that is, more than 100 times its own volume of gases and vapors. When one realizes the explosive power which this implies, one may dismiss the introduction of surface waters into the glowing reservoirs of rock from the theories of volcanic action."

I will, however, bring these matters in as important factors in the production and circulation of underground waters and the formation of ores; and, so long as their original presence in the igneous rocks is admitted, it is a matter of small moment, in this connection, whether the magmas are brought up into the zone of circulating waters by gravity, according to the views of Dutton, Gilbert and Van Hise, or by the exhaustive force of the once occluded vapors themselves, as other authorities of equal weight maintain.

The general conception also gains much support from what we know of the contact-deposits which are found on the borders of eruptive rocks and limestones. Mr. Lindgren's paper* bears on this subject. I have recently had the opportunity to study one of the largest of the Mexican cases, and it seems to corroborate the derivation of ores directly from a magma. In the course of the intrusion of a series of eruptives at San José, Tamaulipas (which will be soon described in detail by my assistant, Mr. George I. Finlay), about midway in time, there came a laccolithic mass of andesitic rock which embraced in itself huge masses of Cretaceous limestone. It has produced contact-zones of garnet-rock, with magnetite, a little specular hematite, and great quantities of pyrite and chalcopyrite. All these must be considered to be the products of contact-metamorphism, and, except in the matter of certain minor rearrangements, there is no reason to think that meteoric waters

* "The Character and Genesis of Certain Contact-Deposits," by W. Lindgren, *Trans.*, xxxi., 226, and *Genesis of Ore-Deposits*, p. 716.

have had any share in their production. The limestone, which is quite pure, yielding over 50 per cent. of CaO, as I understand from the smelter-records, has been changed to garnet with something like 15 per cent. of CaO. There must have, therefore, been an enormous emission of SiO_2 and other substances from the magma. Certainly a million tons would be a small estimate of the garnet-rock actually in sight within an area of 2 or 3 square miles. Let us suppose, now, that a magma charged with these materials were intruded in some other rock than limestone, such as sandstone or granite, or some intractable material. The same emission of silica, of sulphur and of metallic bases would certainly take place; but not being able to react on the walls, and not being held by them next to the eruptive, they must migrate upward through fissures. It is, moreover, inconceivable that they should be emitted otherwise than in association with much more steam or potential water than their own mass, and one must believe that they would be yielded under such pressure and with such a *vis a tergo* that they would not need any other motive power to drive them upward. In higher levels, metallic veins with prevailing quartz-filling and all the common varieties of ore-deposits would result. They might mingle with meteoric waters to a certain degree, and beyond question would; but the latter would play no necessary or essential part in the process. The original deposits might be later rearranged by the circulations of meteoric waters, and I realize perfectly, from the recent observations of Messrs. Emmons, Weed, Van Hise, De Launay and others, that there is every reason to believe that they would be; but it is not necessary to assume such arrangements in order to yield an ore-body.

Mr. Lindgren's paper on contact-deposits refers to a number of others similar to this Mexican one, which, in fact, he also cites, quoting a very brief reference to it by Ordoñez; but there are many more. There is a very large one, for example, at San Pedro, N. M., a detailed description of which has been given by two members of the Institute, Messrs. Yung and McCaffery.* I have had the privilege of going over the ground with them the past summer. Notes upon still ad-

* "The Ore-Deposits of the San Pedro District, New Mexico," p. 350 of present volume.

ditional cases have been received from other old students and friends. The very valuable contributions, moreover, of Messrs. Weed and Barrell* upon the Elkhorn district, Montana, have served to show the important preparatory work of contact-metamorphism in producing porous rock wherein ores may later be deposited. Mr. Weed has shown that the Cananea mines, Sonora, Mexico, are of this type; and informally, from Dr. W. L. Austin, the writer has learned of many additional cases.

The recent exhibitions of vulcanism in the West Indies must bring the force of these statements home to any one who reflects upon them. That the sea or any form of meteoric water could have contributed more than a small portion, which was caught up as the explosive vapors progressed toward the surface, seems to me contrary to sound principles in physics. In fact, I cannot resist the conviction that in the study of vulcanism and its effects lies the promising field of investigation which will throw additional light upon the production at least of the first deposits,† which may afterwards experience enrichment in their upper portions from the action of meteoric waters.

The pegmatites and at least their limiting quartz-veins were certainly produced in very much the way just outlined. They are very widespread. Mr. Lindgren mentions the general experience that they are barren of ores,‡ and I have likewise remarked this feature;§ but Dr. O. A. Derby has recently contributed to the Institute some notes on Brazilian gold-veins in which he describes a very extensive series of rather richly productive veins of this character.||

If, now, we add to the above considerations the further one of the almost constant association of eruptive rocks with veins,

* "Geology and Ore-Deposits of the Elkhorn Mining District, Jefferson Co., Mont.," by W. H. Weed; "Petrography," by Joseph Barrell, 22*d* *Ann. Rept. U. S. Geol. Survey*, Part II., p. 399. "Physical Effects of Contact-Metamorphism," by Joseph Barrell, *Am. Jour. Sci.*, April, 1902, p. 279.

† A very suggestive essay bearing on this point is that of L. De Launay, "Contribution a l'Étude des Gîtes Métallifères," *Annales des Mines*, August, 1897, p. 119.

‡ "Character and Genesis of Certain Contact-Deposits," *Trans.*, xxxi., 243, and *Genesis of Ore-Deposits*, p. 732.

§ "Rôle of the Igneous Rocks, etc.," *Trans.*, xxxi., 183, and *Genesis of Ore-Deposits*, p. 694.

|| "Notes on Brazilian Gold-Ores," p. 282 of present volume.

and the usually very restricted occurrence of the latter, it seems to me that, areally considered, we have adequate reason to attribute to the former, and especially when there is no positive contradictory evidence, very great importance in vein-production. It is reasonable, efficient, demonstrated in important cases, and in no respect more speculative than the inferred deep circulations of descending meteoric water. I do not state this controversially, but as a claim for its recognition.

When ore-formation is referred to pneumatolytic or fumarolic action, I understand that practically these processes are meant. Under these names, or with a general statement similar to the one given above, the processes have been often appealed to.* Nevertheless, such unquestioning faith has generally been felt in meteoric waters that the possibilities of this general cause have received comparatively little attention.

B. Regarding the general question of the descent of meteoric waters into the earth, there developed in our two papers considerable difference of opinion between Professor Van Hise and myself. I am entirely frank to admit that I gained from his "Principles" the idea that he believed the meteoric waters to be everywhere descending, migrating laterally through the smaller waterways, and, although guided by relatively impervious beds, pitching anticlines, etc., to be then returning to the surface by the trunk-channels. This is certainly the conception of the ground-water hitherto held by the lateral-secretionists. I have again and repeatedly read the parts of the essay bearing on this subject, and I cannot blame myself for reaching this conclusion. I therefore laid stress, and with entire justification, upon the dryness of deep mines, in order to delimit or disprove it. Professor Van Hise's rejoinder† to my arguments strikes me as a great restriction upon what I believed to be his conception, and, were it not for his statement to the contrary, I should conclude that his attitude had been much modified. The latter expression makes it less difficult for us to attain

* For instance, by von Richthofen for the Comstock lode; by J. S. Curtis for Eureka, Nev., Monograph VII., *U. S. Geol. Survey*, p. 89; and by Arnold Hague, Monograph XX., 294; by J. E. Spurr for Mercur, Utah, 16*th Annual Report*, *U. S. Geol. Survey*, Part II., p. 402; and by the last named, again, in the 18*th Annual Report*, Part III., pp. 297 to 316.

† *Trans.*, xxxi., 300 and 301.

approximate agreement. I am quite free to admit that it is possible that the advance of "cementation" may plug up cavities so as seriously to impede circulation. This would be especially effective in the larger channels where the main ore-bodies such as we mine are precipitated. If, then, a mine went down on a filled and plugged vein, water might reasonably diminish and disappear with depth. It is less easy to believe that the same results would take place in the smaller and tributary conduits which feed downward and into the larger up-takes, because they must be kept open in order to bring in material wherewith to plug the latter. If, then, deep shafts in a district of heavy rainfall like the copper region of Keweenaw Point, before reaching the ore-body, cut nearly a mile of strongly inclined lava sheets, a hundred or more in number, and many of them amygdaloidal, without finding water below a comparatively shallow depth, it proves that rocks are ordinarily much more impervious than has been supposed in most discussions in the past regarding the descent of meteoric waters. I learn from friends who have been in the Transvaal gold regions that the deep shafts there, which, as we all know, are sunk through one flank of a syncline of sedimentary strata, likewise find dry ground at a depth of about 250 ft. Aside from any bearing upon Professor Van Hise's essay, I think it is important to emphasize these points. I am frank to admit that I did not fully appreciate the force of this observation myself until I came to prepare the paper on the "Rôle of the Igneous Rocks;"* and yet, despite the force of Professor Van Hise's reply, I cannot say that I believe that the damaging effects of experience in deep and dry mines upon our older conceptions of the descent of the meteoric waters (conceptions which I have held in common with geologists in general) have been satisfactorily met by Professor Van Hise in advancing the idea of the zone of cementation. The dryness of deep mines destroys for a large part of the earth the very foundations of Professor Van Hise's main contention; and in meeting this objection with the conception of the zone of cementation he may well be, as it seems to me, merely opposing a damaging ma-

* *Trans.*, xxxi., 169, and *Genesis of Ore-Deposits*, p. 681.

terial fact with a largely subjective conception. I am led rather to have the more confidence in the intrusive rocks and their emissions. In this connection it may be of interest to remark that in a paper in vol. vi. of the *Transactions*, pp. 544 and 545, 1877, Dr. Raymond has outlined briefly both sides of this discussion.

Let us, however, admit that, after periods of upheaval and special fracturing, the meteoric waters descend with all the facility and in all the abundance required by the conception formulated by Professor Van Hise. According to this, as I understand it, the cause of their return to the surface from the depths, which, as the extreme, are about 10,000 meters, is the "head," or the amount by which the pressure at the base of the descending columns exceeds that at the base of the corresponding ascending columns. The head is chiefly due to the greater length of the former column, because it is fed from entrance-points which are above the points of emergence of the returning waters; but the head is reinforced by the expansion produced in the ascending and hotter column because of increments of heat absorbed at a greater or less depth within the earth. The motive power is, however, the head in all cases; that is, it is gravity. I do not for a moment question the force or attractiveness of this conception, nor the able way in which it has been presented by Professor Van Hise, even though I have not the same faith in its efficiency which he evidently feels.

It is clear that if "head" is at all active, there must be a continuous and unbroken column of water from the surface, or from very near the surface, to the ultimate depths reached by the meteoric waters, and back again to their point of emergence. This pressure or head must be transmitted through all the cavities, small and large, capillary, subcapillary and supracapillary, which the waters traverse. It seems to me to demand, where it operates, practical saturation of the crust of the earth with water,—a condition which experience in deep mines proves to exist, so far as I know, in no mining-region to-day, except, perhaps, in one or two of obvious expiring vulcanism. Despite the conception of the zone of cementation, earlier referred to, I am influenced by this experience.

In discussing the transmission of pressure through cavities of capillary size by the descending waters, I regret that I did do Professor Van Hise an unintentional injustice, as he remarks in his closing discussion, in that I confused the passage of the descending waters under pressure, through capillary tubes, with capillarity or capillary attraction. The interposition of the latter would destroy "head," but the interposition of the former would only greatly reduce it because of friction,—a point emphasized by Professor Van Hise.

There is no question that, if meteoric waters enter a fractured and open-textured portion of the earth, descend, migrate laterally in unbroken course, and meet uprising fissures which reach the surface at lower points than the place of entry, they must emerge and establish a circulation. The points open to argument are, first, the extent and relative amounts by which the different sources of internal heat may aid them or substitute a source of energy even greater than "head" or gravity; second, whether they are, on the whole, as efficient causes of vein-formation as intruded rocks and their emissions; and, third, whether the general geological relations of veins support one view or the other, and to what extent. In taking up the first point, I revert to the blocking out of the sources of internal heat mentioned above as 1B, 2B and 3B, which are essentially the same as those mentioned by Professor Van Hise in his "Principles" (*Trans.*, xxx., 49). The second and third points I have already discussed in my previous contribution.

1B. Doubtless the crushing of rocks under dynamic stress and chemical reactions develops heat, but to what extent I do not know, nor does this source seem to me to be capable of more than this general expression. The development of interior heat by chemical reactions shares the same indefiniteness.

2B. As to the part which the normal increase of temperature plays in aiding terrestrial circulations, it is possible to reach a more accurate quantitative expression. The heat which will raise the temperature of a column of water from 4° C. to 100° C. will produce an expansion of about 4 per cent. and a consequent diminution of density. This calculation is used, with subsequent general modification to meet terrestrial condi-

tions, by Professor Van Hise.* I brought against it the objection that this expansion would be neutralized by the pressure of the accumulating column of water, which, to a height of about 10,000 ft., would rest upon that portion which would attain a depth in the earth where the temperature would be 100° C. While I did not have at hand the data for an exact expression, I had submitted the proposition to a friend who could give an authoritative opinion and had been assured that the modification was well grounded. I stated, therefore, that it would practically prevent effective expansion and loss of density. This statement is too sweeping, and Professor Van Hise's objection in the Discussion† is well taken. Professor William Hallock has kindly given me the following references,‡ in which it is stated that the cubical compression of water at 4° C. is 0.0000469 per atmosphere. Assuming that this holds good for all temperatures up to 100° C., it means, in a column of 10,000 ft. in height, which would create a pressure of about 5000 lbs. to the square inch, a compression of about 1.6 per cent. at the base, leaving 2.4 per cent. of the original 4 there effective. If, again, the data given by Dr. Carl Barus, and cited by Professor Van Hise,§ are taken, the results are not greatly modified. Dr. Barus determined the compression of a capillary column of water, 17.4 c.m. in length and at a temperature of 23° C., to be, for 83 atmospheres, .0037; for 160 atm., .0075; for 226 atm., .0108. If we continue it at the same rate for 340 atm. (or 10,000 ft.), it is .0165 or 1.65 per cent. At 100° C., on a capillary column 18.1 c.m. long, Dr. Barus determined it to be, for 83 atm., .0046; for 180 atm., .0098; for 244 atm., .0133. Continuing at the same rate, it would be, for 340 atm., 1.84 per cent. at the base.

Since we assume that the increment of temperature and the increment of pressure are each uniform in descent, we may say that for an increment of 96° C. we have an expansion of 4 per cent., or $\frac{1}{24}$ of 1 per cent. for 1°. At the same time we have

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* *Trans.*, xxx., 49, and *Genesis of Ore-Deposits*, p. 304.

† *Trans.*, xxxi., 296.

‡ W. Watson, *Textbook of Physics*, p. 182. Wüllner, *Lehrbuch der Physik*, vol. i., p. 275. Johann Müller, *Lehrbuch der Physik*, vol. i., p. 139.

§ *Trans.*, xxxi., 296.

a compression of 1.6 per cent., or, expressed in the rate per degree of increased temperature, $\frac{1}{60}$ of 1 per cent. The net expansion per degree expressed in per cents is therefore $\frac{1}{24}$ minus $\frac{1}{60}$ or $\frac{1}{40}$.

It is now not difficult to reach a quantitative expression of the actual efficiency of the normal increase in temperature in promoting hot-springs. We may assume a mean annual temperature at the surface of the earth of 10° C. For comparison, at New York it is 10.6. If a descending column starts at 10° and ends at 100°, its mean temperature will be 55°. Mr. G. K. Gilbert has found, as quoted by Professor Van Hise, that the waters of the hot-springs in the Cordilleran region range from 37° C. to 100° C., and that those of the much more abundant warm springs range from 18° to 37°. There is little doubt that many of these, and probably all the hotter ones, are connected with expiring vulcanism and have no bearing upon this immediate discussion. If, therefore, we assume springs emerging at 20°, 30°, 40°, and so on to 100°, we shall cover the essential cases in Nature. In the calculation we must use the mean temperatures of ascending columns which start at 100° C. and reach the surface at the above temperatures, and we may express the whole matter in a small table, recalling that, for each increase of 1° in the mean temperature of the uprising column, as compared with that of the descending one, there results an expansion of $\frac{1}{40}$ of 1 per cent., which, expressed in feet for a 10,000-ft. column, is 2.5 ft.

TABLE I.—*Mean Temperature of Descending Column*, 55° *C.*

Temp. of Emergence. Centigrade Degrees.	Mean Temp. of Ascending Column. Cent. Deg.	Excess of Temp. Cent. Deg.	Increase of Head.	
			Per Cent. Expansion.	Feet.
20	60	5	$\frac{1}{8}$	12.5
30	65	10	$\frac{1}{4}$	25.
40	70	15	$\frac{3}{8}$	37.5
50	75	20	$\frac{1}{2}$	50.
60	80	25	$\frac{5}{8}$	62.5
70	85	30	$\frac{3}{4}$	75.
80	90	35	$\frac{7}{8}$	87.5
90	95	40	1	100.
100	100	45	$1\frac{1}{8}$	112.5

When we consider how slight an increase this amounts to in a 10,000-ft. column, which is fed by all sorts of small tributaries with high friction; and when we compare the results with the vastly greater head resulting from inequalities of the ground which would almost pass unnoticed; when, again, we recall the rarity of hot-springs having even the moderately elevated temperatures and not obviously in volcanic or eruptive regions; and when we realize that any ascending column would inevitably draw to itself by induced currents much colder water in the rocks toward the surface, I think we are justified in practically dismissing the normal increase of temperature in the earth as of any essential importance in helping to force descending meteoric waters through the devious underground passages. We must have a head contributed by a higher source at the point of entry, and therefore a continuous column of water, or we must have local supplies of heat from recently intruded igneous rocks.

Again, if we have a region where the rate of increase of the interior temperature is less than the basis of the above calculation, viz., 1° C. for each 30 meters (1° F. for each 55 ft.), as, for instance, Keweenaw Point, where the rate is very nearly 1° C. for 60 meters (1° F. for each 100–110 ft.), or the Transvaal, where, as I learn from Mr. Pope Yeatman, preliminary experiments have shown an even slower rate, then the force of my argument is doubled. And if the mean annual temperature is higher than 10° C., the argument is thereby correspondingly strengthened. Naturally, also, a colder mean annual temperature weakens the argument, but not proportionately, since water is densest at 4° C., leaving a range of but 6° for mean annual temperature as between this and the 10° assumed above, before the limit is reached.

I realize that the expulsive action of the normally heated interior was only a minor point in Professor Van Hise's argument, and it is not with reference to his paper that these conclusions are specially urged, but because it is probable that generally, among geologists, much greater efficiency is attributed to this agent than it would seem to deserve. All these considerations make us fall back with the greater reliance on igneous rocks as sources of heat and energy for promoting circulations

which reach the surface. The influence of the increase of temperature in the normal ratio must be mainly one of magnifying chemical efficiency in those meteoric waters which come within its influence.

In this connection I cannot refrain from referring with the greatest admiration to Mr. Weed's recent paper on "Mineral Vein-Formation at Boulder Hot Springs, Montana."* It is of the highest significance, both in reference to the topic here discussed and to the one next to be taken up.

3B. If we imagine a mass of molten igneous rock injected from below into the upper regions where the meteoric ground-waters exist, a new factor is introduced of enormous efficiency. The molten rock may be considered as having a temperature of about 1200° C. (about 2200° F.). Its influence in expanding to the full limit of the liquid condition any meteoric waters within the sphere of its influence would be relatively abrupt, and its effect in increasing normal head would be pronounced. If it sufficed to change to vapor any of these waters, their density would be enormously lowered and the head would be still more effective. But even apart from the head of the descending column, and even without assuming its existence with reference to waters at the place in question, for meteoric waters may be present even if not under a continuous column to the surface, the expansive force of the steam, or even of the dissociated gases, reinforced by the copious emissions of the eruptive, would start circulations toward the surface, and, as it seems to me, would be a most efficient agent. This is what I have referred to in my paper and elsewhere as contributions of energy, and the process has been indicated by describing intrusive rocks as stimulators of circulation.

Gradually the intrusive rock cools and becomes a less and less efficient cause, and in the end it assumes the normal temperature for that portion of the earth in which it is situated. Possibly circulating waters continue their migrations, urged on by head, and are effective in depositing ores. Possibly, also, they practically cease, and the period of ore-deposition corresponds to the period of efficiency of the eruptive. I am

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* *Twenty-First Annual Report U. S. Geol. Survey*, II., 227.

strongly inclined to believe the latter view is correct, and that when the fires under the boiler are quenched, the engine ceases to run.

Do we, then, find mineral veins provided with ores in those places where, once in a million times, the combination of precipitating agent and metalliferous solution meet under favorable conditions in the circulation of the meteoric ground-waters? or do we find them where, down under the surface, some intrusive rock has entered charged richly enough with a metallic burden to impart it to uprising heated waters and yield a series of ore-bodies? From the experience gained in western mining-districts the latter appeals to me the more forcibly, and I am inclined to believe that original ore-deposition ceased, not so much because cementation plugged the conduits as because the energy of the stimulating cause became exhausted. But even in making this guarded statement, I trust that I do not fail to appreciate the extent to which the whole matter is speculative and inferential,—a phase of the subject adequately emphasized, and I think alone adequately emphasized, in my previous paper.

There remain but one or two other points which seem to me to deserve attention beyond the treatment given them in the "Rôle of the Igneous Rocks, etc." There is some difference of opinion between Professor Van Hise and myself regarding the abundance of veins. While I have the greatest respect for his very wide experience and observation, I nevertheless am strongly of the opinion that, if we leave out pegmatites and their related quartz-veins, which are so extensively developed in metamorphic districts, veins of any sort, commensurate in size with those which we mine, are quite rare phenomena, and, though locally abundant, are yet, on the whole, but seldom seen. This is not alone my own opinion, but that of friends in the practice of mining engineering, and of greater experience in these matters than either Professor Van Hise or myself. Unless some very restricted cause has occasioned them, they ought to be far more abundant than they are.

As to the presence of the ground-water in all mining-regions, an additional word may be of interest. There certainly are localities in the arid region of the West where, at considerable

depths, it has not yet been met in notable amount, and where its distribution is very irregular. At Tintic, Utah, for instance, as I am informed by Dr. W. P. Jenney, the Mammoth-Tintic workings are 2000 ft. deep in the limestone. They have never used a pump nor have had more than a little drip of water in a few places. The ores are oxidized and the bottom levels are perfectly dry. The ground-water may be encountered in time, but it is certainly very deep. One or two miles away, in the monzonite, water is met within 100 or 200 ft. of the surface—not in great quantity, indeed, but sufficient to have prevented the oxidation of the ore. Over the divide from the Mammoth, and beginning 550 ft. below it, are the Bullion-Beck and Gemini mines. Their shafts are down 1660 ft., and from very large and extended workings, and of course with no attempt to impound the water near the surface, they gather about 10 gallons a minute,—no more than can be readily removed by a bailer once in a while through the day. The ores are all oxidized.

The Horn-Silver mine at Frisco is down 1600 ft. and is practically dry; the ore is oxidized. Water for the camp is, of necessity, brought in from a distance. I realize that Mr. Emmons has stated in his paper* that some water is met, but the quantity is so small that the present management is sinking a bore-hole from the bottom of the mine in the hope of tapping enough, at least, to furnish a supply for the boilers.

My friend, Mr. John N. Judson, has given me some interesting notes on the Mapimi mines in Mexico. The mines were dry to a depth of over 760 meters, or about 2400 ft. Some dampness was first observed in the wall-rock, and later some water appeared in the veins, which are chimneys in limestone. Whether the workings will pass through this wet ground (it is not very wet) and again reach dry rock will be one of the interesting things for the future to determine.

In a review of the separate volume on "The Genesis of Ore-Deposits," recently issued by the Institute, Mr. H. F. Bain, in the *Journal of Geology*, May–June, 1902, p. 434, emphasizes

* "The Delamar and the Horn-Silver Mines," by S. F. Emmons, *Trans.*, xxxi., 658.

the importance of considering, in this connection, only vertical depths, and not the relatively flat inclines, which, while long and perhaps dry, may not attain great depth nor be significant. I believe all the cases cited by me have been of vertical shafts. Mr. Bain also mentions experience in the Newhouse tunnel, in cutting wet veins, as indicating the presence of water at great depths. To this, however, it may be replied that a tunnel into a mountain merely produces an artificial spring; that springs exist along almost all valleys, and their water at times certainly comes from considerable depths; but my contention is that, so far as actual experience goes, in very deep mining, water is scarce or almost unknown unless there is expiring vulcanism. From this it follows that the igneous rocks are probably the important factors in deep circulations.

Regarding points like these, it is most desirable that members of the Institute should place observations on record.

In closing, I may add that, although I apparently differ with Professor Van Hise regarding the relative importance of certain factors in the problem, there is no one who has a higher admiration for his essay than myself, a feeling which, as a matter of fact, I had elsewhere expressed before the Richmond meeting. At the same time, a somewhat extended correspondence has shown that not a few mining-geologists in America and elsewhere are in sympathy with the points emphasized in my paper, and with the relative importance there attached to the several factors.

Ore-Deposits Near Igneous Contacts.

BY WALTER HARVEY WEED, WASHINGTON, D. C.

(New Haven Meeting, October, 1902.)

CONTENTS.

INTRODUCTION.

THIS paper deals with certain ore-deposits whose structural features or mineral contents (or both) result, directly or indirectly, from igneous intrusions and their after-effects. It is largely a discussion of contact metamorphic ore-deposits based upon the physical changes in rocks due to contact action. It involves a classification of ore-deposits only so far as is abso-

lutely necessary for brevity of discussion. A genetic classification of ore-deposits is admitted to be the rational and only correct classification from a scientific point of view. To the practical miner, such a classification may be of utility if the correct discrimination of the nature and genesis of a deposit enables him to more nearly determine the probable extent and value of the deposit, and to exploit it intelligently. It is believed that the facts set forth in this paper and the explanation of them admit of such a practical use.

Why Ore-Deposits are Common about Igneous Contacts.

As is well known, the granitic rocks which adjoin contact areas are parts of great masses of igneous magma which did not reach the surface, but cooled slowly underground and consolidated into coarse-grained rocks. Subsequent uplift and denudation have exposed both the great bodies of igneous rock, and the sediments baked and altered by them, in consequence of the heat and vapors given off by the cooling magma.

Igneous contacts are ore-bearing because, (a) differentiation of the cooling magma tends to segregate the highly basic and metal-bearing portion at the border of the cooling mass; (b) pneumatolytic processes are most active about the borders of igneous masses; (c) the force of the intrusion may have shattered the adjacent rocks, forming cracks and fissures that become channels for circulating waters; (d) the shrinkage of the intrusive magma due to progressive cooling after solidification, and the shrinkage of the metamorphic zone itself, would result in the formation of fissures; and (e) as will be shown later, the porosity induced in certain sedimentary rocks by contact metamorphism (which may be compared to the burning of clay into brick) has furnished channels for circulating waters and gases, so that ore-deposition has resulted. The origin and character of the latter class of deposits is the only strictly novel feature of the paper. The deposits formed near igneous contacts by the operation of these causes have widely different characters. To discuss them a systematic arrangement is necessary, and the following provisional genetic classification has been proposed.*

* Compare *Eng. Min. Jour.*, vol. lxxv., No. 7, p. 256, Feb. 14, 1903.

OUTLINE OF A GENETIC CLASSIFICATION OF ORE-DEPOSITS.

I. Igneous (magmatic segregations).
  A. Siliceous.
  B. Basic.

II. Igneous-emanation deposits (deposited by highly heated vapors and gases in part above the critical point, *e.g.*, 365° and 200 atm. for H_2O).
  A. Contact-metamorphic deposits.
  B. Veins (closely allied to magmatic veins and to division IV.).

III. Fumarolic deposits (metallic oxides, etc., in clefts in lavas; of no commercial importance).

IV. Gas-aqueous (pneumato-hydato-genetic) deposits. Igneous, gaseous and aqueous emanations, alone or mingled with ground-waters.
  A. Filling-deposits.
  B. Replacement-deposits.

V. Deposited by meteoric waters.
  A. Underground.
  B. Surficial.

In this classification I have attempted to group the geological processes forming ore-deposits in such a way as to show genetic relations, it being understood that opinions will differ as to the class to which a particular deposit is to be assigned.

Major subdivisions are based upon magmatic segregations at one end and cold aqueous deposits at the other, with intermediate groups due to the emanations from igneous rock, the eruptive after-actions of Vogt, to which the term pneumatolytic has commonly been given; fumarolic, when these emanations issue at low temperature and pressure; gas-aqueous, in which the emanations from igneous rocks, with their burden of metals, mingle with ground-water; aqueous, in which meteoric waters alone are active, both chemically and mechanically.

Ores of Igneous Origin.

The igneous deposits are divided into basic and siliceous, the former including the deposits of iron, copper, etc., found at igneous borders and as dikes, the latter the ore-bearing pegmatites, with quartz-veins as extreme examples.

The existence of certain ore-deposits of an igneous origin seems to be fully proven and generally accepted. It is well known that the igneous magmas differentiate into siliceous and basic portions,* the resulting rocks being the siliceous aplites (alaskites) and highly basic rocks of various kinds. Where extreme differentiation has taken place, the basic residual portion contains so much iron or copper solidified as to form workable ore-deposits, constituting the subdivision B of the table. The same extreme segregation would produce the siliceous magma commonly seen as acid granites or aplites, which frequently pass into pegmatites, and the latter, in turn, into quartz-veins. These facts are well known.†

Some of these observers, however, believe that pegmatites and allied quartz-veins are due to igneous emanations of watery vapor, and are not direct segregations. Whatever may be the result of further study concerning the origin of these interesting veins, there is no doubt that in part, at least, they are of pneumatolytic origin. There is, however, abundant evidence to show that acid rocks are commonly associated with gold-deposits. Richard Beck, in his book on ore-deposits, describes the occurrence of intrusive bodies of granite near Lake Schartash which carry gold; and various observers have described dikes of similar acidic granite at Berezovsk containing quartz filling contraction-cracks, and consequently a normal constituent of the rock, which are mined for their gold values. In a treatise entitled "Criaderos Minerales de Mexico," Aguilera has given very many examples of the association of ores with extremely siliceous rocks.‡

In a general way, the laws of segregation outlined by Pirsson indicate that we should expect the siliceous segregation in the center of the igneous mass and the basic ones at the borders, while the basic dikes would traverse the igneous contacts, cutting both the igneous rock and the adjacent altered sedimentary rocks.

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* Weed and Pirsson, "Shonkin Sag Laccolith," *Amer. Jour. Sci.*, July, 1901.

† Kemp, "Role of the Igneous Rocks in the Formation of Veins," *Trans.*, xxxi., p. 182; also, *Genesis of Ore-Deposits*, p. 693. Van Hise, *Trans.*, xxxi., p. 287. Lindgren, "Character and Genesis of Certain Contact-Deposits," *Trans.*, xxxi., p. 243; also, *Genesis of Ore-Deposits*, p. 733. A. W. Howitt, *Roy. Soc. Vic.*, Oct. 14, 1886.

‡ "Distribucion Geográfica y Geológico de los Criaderos Minerales de Mexico," José G. Aguilera, *Acad. Sci. Off. Secretario Fomento*, Mexico, 1901.

Igneous-Emanation Deposits.

Under this title I have grouped contact-metamorphic deposits and pneumatolytic veins. The contact-metamorphic deposits have been shown by Vogt, Lindgren, Beck and others to be formed under conditions which preclude either the presence of ordinary ground-water or steam at low temperature and pressure.

Pneumatolytic veins, of which the Cornwall tin-veins are classic examples, are admitted by most competent observers to be formed by igneous emanations proceeding from the still hot granite rocks.* The group includes part of those embraced in Vogt's "Ore-Deposits Formed by Eruptive After-Actions."

The contact-metamorphic deposits are treated at considerable length in the succeeding pages.

Fumarolic Deposits.

Under this group I have classed deposits of ferric chloride, cuprous oxide, and other metallic minerals formed in clefts of volcanic craters. Deposits of this kind have been observed by Geikie and many other geologists, and the evidence concerning them is summarized in discussing the origin of contact-metamorphic deposits. They are assigned to a separate class because they are formed at the surface of the earth under conditions which do not and cannot prevail in depth.

Gas-Aqueous Deposits.

This group is formed to include those ore-deposits formed by hot waters containing metallic salts and other substances derived wholly or in part from igneous emanations. This class of deposits corresponds closely to Vogt's igneo-aqueous or eruptive-after-action group,† but it is as well to emphasize the distinction to be made between hot waters carrying only the substances dissolved out of the rocks traversed by them and those charged with substances undoubtedly derived from igneous emanations. The evidence concerning these deposits has been very ably summed up by Suess in his recent paper.‡ Professor Suess

* *Zeitschf. Kryst. u Min.*, vol. xvi., 1890. † *Trans.*, xxxi., p. 125 *et seq.*

‡ "Ueber Heisse Quellen," *Gesel. Deutsch. Naturforscher und Arzte*, 1902.

expresses his belief in the inability of ordinary circulating waters to derive the unusual substances, such as boron, fluorine, chlorine, etc., from ordinary igneous and sedimentary rocks. In fact, Professor Suess goes further, and says, the water of the famous hot springs of the Carlsbad region is original or primitive water derived from the underlying igneous hearths and containing little, if any, meteoric water. On the other hand, there seems to be no question but that in many instances circulating meteoric waters intercept the uprising primitive waters, and the solutions thus formed deposit ores. In such cases the meteoric waters are the vehicle and not the agent. This has been concisely stated by Lindgren as follows:

"Where fissures traverse the cooling magmas and the rocks surrounding them, it is natural that these mineralizing agents (emanations), carrying their load of heavy metals, should ascend, at first under pneumatolytic conditions, above the critical temperature. Reaching the zone of circulating atmospheric waters, it is natural that they should mix with these, which probably greatly predominated in quantity. To this combination of agencies, found in the ascending waters of such regions of igneous intrusion, the formation of most metalliferous veins is probably due."*

Deposited by Meteoric Waters.

Under "Underground Deposits" I have grouped the deposits formed by circulating ground-waters in one class; those of residual origin, being leached veins, in an entirely separate class; as surficial deposits I would include *chemical* deposits of various kinds, and *mechanical* deposits, such as sedimentary rocks, placers, etc.

Believing, with Professor Kemp, that the greatest number of copper and precious-metal deposits of the world are near igneous rocks with which they are genetically connected, I hold, with Vogt, that normal terrestrial water-circulation has had a minor part in the primary origin of the deposits in question, though it may have produced later concentration from contact portions of the magmas rich in metals or from low-grade deposits of direct contact-metamorphic origin.

Contact Metamorphic Deposits.

Under the title of contact metamorphic deposits I include all ore-deposits which result from the metamorphic action of

* *Trans.*, xxx., p. 692.

intrusive igneous rocks upon the sedimentary rocks which they penetrate. Such deposits occur only in the zones of altered sediments about igneous intrusions; they are genetically connected with such intrusions, and are, therefore, fittingly designated as ore-deposits of contact metamorphic origin. The following subdivisions are proposed:

Deposited by Igneous Emanations.

(All classes omitted save the one under discussion.)

Contact Metamorphic Deposits.

Characterized by gangue consisting essentially of garnet, epidote, actinolite, calcite, and other lime-alumina silicates.

(a) Deposits confined to contact:
1. Magnetite deposits.
2. Chalcopyrite deposits, Kristiania type.
3. Gold-ores, Bannack type.

(b) Deposits impregnating and replacing beds of contact zone:
1. Chalcopyrite deposits—(a) Pyrrhotite ores, (b) magnetite ores, Cananea type.
2. Gold tellurium ores, Elkhorn type.
3. Arsenopyrite ores, Similkameen type.

In the present paper I shall particularly describe certain ore-deposits occurring in sedimentary rocks altered by contact metamorphism, and endeavor to show that thermal metamorphism effects certain physical changes in the sedimentary rocks of the contact-zone favorable to ore-deposition, either because the vapors and gases of the cooling magma penetrate the altered rocks and deposit metallic sulphides or by reason of a later impregnation, by circulating waters, of particular strata, *made porous by thermal metamorphism.* They, therefore, embrace both the "contact"-deposits of the Kristiania type and the types herein described, and which have been called bed-impregnations by Dalmer* and "Strikes" by Beck.† These embrace the Cananea type and the types of gold-deposits, heretofore unknown, which structurally and genetically resemble the first types mentioned, but differ in mineral contents.

* "Problems in the Geology of Ore-Deposits," *Genesis of Ore-Deposits*, p. 650; also, *Trans.*, xxxi., p. 139.

† Richard Beck, *Lehre von den Erzlagerstätten*, 1901, p. 485.

As the admirable treatise of Lindgren* presents a discussion of contact metamorphism in describing the genesis of deposits of the Kristiania type, much concerning this subject may be profitably omitted from the present paper, though it is necessary for a clear understanding of the subject to give an outline of the principal facts.

Contact Zones.

In many mining districts there occur great masses of granitic rocks, surrounded by sedimentary strata which, near the contact, exhibit marked alteration, the intensity of which diminishes as the distance from the igneous rock increases until the alteration fades out and the rocks are of normal character. Such areas are known as contact metamorphic zones, which often form a halo about igneous centers; for example, about the "stocks" of granitic rocks of the Crazy Mountains, Montana, or the batholitic masses of the Black Hills, Dakota. In other cases great areas of granitic rock, such, for example, as the great mass of granite called the Butte batholith, of Montana, which is 60 miles long and 40 miles broad, are bordered by a zone of rocks altered by contact metamorphism which may be a mile or more wide, as, for instance, near Helena, Montana. Such contact zones are often the seat of mineral deposits of great economic value, as is illustrated by the Drumlummon and other mines at Marysville, Montana; several mines at Granite and Phillipsburg, Montana; the Whitlatch-Union and other mines, once productive, at Helena; the copper-mines at Clifton and Morenci, Arizona; those at Cananea, Sonora, and many other localities in Mexico. I exclude the common contact-deposits of the text-books, in which it appears probable that the igneous rock has, by its presence, localized and deflected circulating waters and thus determined the site of ore-deposition.

Character of Gangue.

Contact metamorphic deposits of whatever type are distinguished by a gangue consisting essentially of garnet, calcite, epidote, actinolite, with or without accessory wollastonite, vesu-

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* "Metasomatic Processes in Fissure-Veins," *Genesis of Ore-Deposits*, p. 498, 1901; also, *Trans.*, xxx., 578.

vianite, fluorite, etc., and other minerals characteristic of contact metamorphic zones. As will be shown later, the gangue is normally a rock formed by the alteration of an impure limestone. Other rocks characteristic of contact action, such as hornfels, marble, quartzite, adinole, etc., are often present, but the ore-deposit is practically confined to the rocks resulting from the alteration of impure limestones, for reasons explained later.

Character of Ore-Deposit.

The Kristiania type of contact-deposit has already been described by Lindgren.* Specular iron and magnetite are common in true "contact"-deposits, but they occur only rarely in the deposits separated from the contact. The ore-minerals present considerable variety, and according to their metallic contents may be grouped as copper-ores and as gold-ores. A more complete classification would be, however,

(1) Chalcopyrite deposits: (a) pyrrhotitic type, (b) magnetic.
(2) Telluride deposits.
(3) Arsenopyrite deposits.

The first class includes the chalcopyrite ore-bodies carrying accessory galena at Cananea, Mexico. The subtypes are distinguished at Boundary, British Columbia. In the pyrrhotite type that mineral predominates, but the copper values are in chalcopyrite and accessory pyrite, while in the magnetite type this mineral replaces pyrrhotite. The second class is characterized by the presence of telluride of gold. In the Elkhorn example the ore-mineral is an auriferous tetradymite with associated bismuthinite. At Bannack, Mont., there is free gold, with much more abundant sylvanite. In the third class arsenopyrite occurs, carrying very high values in gold, together with free gold. The only known example of this class is the Nickel Plate mine, near Lake Okanagan, British Columbia.

The characteristic feature is the gangue of earthy silicate minerals in which the ore-minerals are disseminated. In most cases the ore-minerals and the sulphides are of simultaneous origin (or nearly so). The deposits are the direct result of the deposition of ore by the vapors and gases of the cooling magma

* "Character and Genesis of Certain Contact-Deposits," *Genesis of Ore-Deposits*, 1900, p. 716; also, *Trans.*, xxxi., 226.

(possibly, in part, the gases given off by the alteration of the sediments).

Literature.

Geologists have long recognized the peculiar characters of ore-deposits in the contact metamorphic zone about igneous intrusions, nor would it be possible for a careful observer to fail to note the successful mines and the multitude of unsuccessful prospect-pits which commonly mark such areas. It is unnecessary to go into detail on this subject, as it has been covered by Lindgren in the paper cited.* It is evident that Kemp,† although grouping contact metamorphic deposits as contact-deposits, recognized their individual character, as shown by the examples given under that head in his classification, though he gives no details of occurrence nor shows their difference from those of the Kristiania type.

Despite this very general recognition of such deposits, no discrimination was attempted until Von Groddeck defined contact-deposits of the Kristiania type, showing that they formed a distinct and separate class of ore-deposits, differing in occurrence and genesis from all other types. The contact metamorphic deposits discussed herein resemble those of this class, though excluded from it by definition,‡ as they are not *contact*-deposits, though quite as truly a result of contact metamorphism. There is a marked correspondence between the two types as regards mineral association and genesis; but the structural differences are so important, and have so marked a bearing, not alone on the theory of their genesis but, also, in the working of the deposits and a determination of their value as mines, that they merit a full discussion.

Geographic Distribution.

Ore-deposits in the zone of contact metamorphism are quite common, though in the past the more noted mines have been fissure-veins whose contents may or may not have been derived from contact metamorphic deposits. As great, massive, igne-

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* "Character and Genesis of Certain Contact-Deposits," *Genesis of Ore-Deposits*, p. 716; also, *Trans.*, xxxi., 226.

† *Ore-Deposits of the United States*, 3d ed., 1902, p. 58.

‡ Lindgren, *Genesis of Ore-Deposits*, p. 717, under heading Position; also, *Trans.*, xxxi., 227.

ous intrusions are most commonly found in regions where periods of great volcanic activity have been followed by uplift and profound erosion, it is in mountainous districts that most contact metamorphic deposits occur.

No attempt will be made to discuss or describe contact-deposits of the Kristiania type. The Jimenez copper-mine, Chihuahua, Mexico,* is a typical example of this class, and the Indian Queen mine at Birch Creek, in Beaverhead county, Montana, is another example, in which later fracturing and enrichment have taken place.

Examples of the Cananea type of contact metamorphic deposits are less common, though the two noted herein are now rated among the most productive mines.

Copper-Deposits—Cananea Type.

British Columbia.—The ore-deposits of the Boundary district of British Columbia have been described by Mr. S. F. Emmons as also of contact metamorphic origin. The deposits are on Boundary Creek, near Greenwood, and comprise the workable ore-bodies of several producing mines. The ores carry 2 to 5 per cent. copper and a few dwts. of gold per ton; but as they occur in very large bodies and are metallurgically docile, they are profitably exploited. The ore-bodies occur in belts of metamorphosed limestones, 2 miles or more wide, that are adjacent to a mass of light-gray, coarsely crystalline, granitic diorite.

The ores consist of sulphides of iron and copper, associated with considerable magnetic oxide of iron, of contemporaneous formation. These minerals occur in a gangue of altered limestone consisting of amphibole, garnet, vesuvianite, zoisite, etc. Microscopic study shows that these are the result of metasomatic replacement, during which a granular limestone has been converted into an amphibolitic rock with the simultaneous development of sulphides and magnetite. From Barrell's studies† I regard it as probable that the action has been the alteration of an impure limestone by normal contact

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* Weed, *Trans.*, xxxii., 396, "Notes on Certain Mines in the States of Chihuahua, Sinaloa and Sonora, Mexico."

† *Am. Journ. Sci.*, vol. xiii., April, 1902, p. 279 *et seq.*

metamorphism. This is also the view held by Dr. A. R. Ledoux.*

According to Emmons,† the ore-bodies are irregular in occurrence, and graduate insensibly in every direction, inward as well as outward, from ore into low-grade rock, the fracture-planes or walls failing to definitely enclose the ore-shoots or define their direction. In this respect they resemble the southernmost ore-bodies at Cananea, but differ from the Cananea type, in which relatively thin beds of impure limestone alternate with less congenial varieties of this rock, so that the ore-strata are fairly sharply defined. The Greenwood deposits are cut by dikes, which may be regarded as the final result of igneous action. As I stated in discussing the genesis of this class of ore-bodies, the process of metamorphism is complete before the magma solidifies; and if the sulphides were introduced during metamorphism they would be cut by the aplite and lamprophyric dikes that represent the final fissuring of the outer mass of chilled magma and filling of fissures from the molten interior.

A later and more detailed account of the ore-deposits of this district by Brock‡ gives further details, and, in part, confirms these observations of Emmons, though presenting very important additions. The ore-deposits are notable for their great size, the Mother lode ore-body being 140 feet thick and developed for 1180 feet in length and 500 feet in depth; the Knob-Ironsides lode is much larger, being 800 feet wide, proven for 800 feet in depth, and several thousand feet in outcrop. Brock distinguishes two types, a pyritic, characterized by pyrrhotite, with chalcopyrite and iron pyrites, and a magnetitic type, with magnetite and copper pyrites. Though segregated in places, the chalcopyrite is remarkably evenly distributed through the deposits. "Rarely do magnetite and pyrrhotite occur in the same deposit."§ Specular iron is found sparingly in a half-dozen properties. Occasionally marcasite, and sometimes arsenopyrite, galena, zinc-blende and molybdenite, are present. Tetrahedrite occurs in one mine and bismuthinite in another.

* "Production of Copper in the Boundary District," *Canadian Min. Inst.*, vol. v., p. 172.

† "Genesis of Ore-Deposits," *Am. Inst. Min. Engrs.*, Special Volume, p. 757.

‡ *Canadian Mining Institute*, vol. v., p. 365, March, 1902.

§ Brock, *Canadian Min. Inst.*, vol. v., p. 368.

The description of the gangue shows red and green garnet and epidote to be abundant in and near the veins, "and the progress of their formation may be observed in many points in all stages, not only when limestone but also when greenstone and granite form the country-rock,"* thus apparently contradicting the hypothesis that such contact minerals result only from the metamorphism of impure limestones. At the Mother lode the marmorized limestones contain the above-mentioned minerals, but the mass of the rock consists of felty actinolite. The gold values are commonly in the chalcopyrite. Magnetite and pyrrhotite, when occurring alone, are commonly almost barren, the Winnipeg pyrrhotite being an exception. There is a lack of veins and stringers enriching the main ore-body, but there appears to be an enrichment of the ore where dikes cross it. The ores are very low-grade, a representative ore carrying copper 1.95 per cent., iron 14 per cent., lime 17 per cent., silica 39 per cent., with 0.119 ozs. gold per ton and 0.44 ozs. silver.

Brock considers the ore-bodies to be composite veins "formed by mineralizing solution traversing the country-rock, principally along fissures or zones of fissures in which they deposit the economic minerals and from which they replace with their mineral contents, particle by particle, sometimes completely, the original material of the country-rock." In the same paper he says, however, that "there seems to be strong reason for supposing the deposits to be connected with eruptive after-actions."

Mexico.—The Cananea copper-deposits, which, during the last year (1901), have been so vigorously exploited that they have produced 140,000,000 lbs. of copper, are situated in the Cananea mountains, 50 miles southwest of Bisbee, Arizona, and 30 miles south of the international boundary-line. This mountain range is from 6 to 12 miles wide and 25 miles long. It rises abruptly from flat or gently-inclined prairies to a height of 8000 feet above sea-level, or 4500 feet above the plain. The range extends in a northwest and southeast direction, and it is bisected, by the low Puertecitos Pass, into two nearly equal parts. The ore-deposits occur in the southern portion of the range.

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* Brock, *loc cit.* This author examined no thin sections, however.

The mountains consist of the dissected and denuded remains of an old volcano, probably of late Tertiary age. At Puertecitos Pass there is a central core of normal granite surrounded by massive andesite and baked and altered sedimentary rocks. The main crest of the mountains southward is formed of marble, hornstone, quartzite and garnet-epidote rocks, resulting from the intense alteration of impure limestone by the heat of igneous intrusions. These rocks are cut by large intrusions of quartz-porphyry and small diabase dikes. The entire range is flanked by foothills and *mesas* formed of well-bedded andesitic tuffs dipping away from the range at angles of from 10° to 30°, and representing the fragmental products of the old volcano, which once formed its cone.

The ores consist of chalcopyrite, together with copper glance, pyrite, zinc-blende, and a little galena. They occur in deposits which are, in part, beds of altered limestone tilted at steep angles and richly impregnated with metallic sulphides, and, in part, deposits formed in fractures along and across the quartz-porphyry and quartzite without any very definite relation to the igneous contact.

Near the Ronquillo smelter of the Greene Consolidated Copper Company the ore-bodies of the group of mines embracing the Capote, Veta Grande, Cobre Grande and Oversight properties occur mainly along these fractures. The outcrops are great ridges of iron gossan, traceable for long distances, and the ore-bodies are very large, one in the Capote being 165 feet by 125 feet, and oval in cross-section. These "veins" conform, however, in dip and strike, to the ore-bodies that consist of beds of altered limestone.

The ore-deposits continue for a distance of about 8 miles along the central portion of the range, and north of the Ronquillo group of mines, just mentioned, they pass into metamorphosed limestones impregnated with copper. In the exposures near the northern part of this area the ore is seen to be confined almost entirely to the garnet-epidote-diopside rocks, which occur interbedded with hornstones, marble, etc.; and, as will be shown later, this accords with the views of their genesis presented herein. In addition to the ore-bodies in course of exploitation, there are many beds that contain much galena and zinc-blende.

These copper-ores are usually very low in gold- and silver-content; but there are certain exceptions to this, notably the Alfreina mine, the ores of which carry high values in gold.

The development work at most of the northerly properties has not yet reached the sulphide ores. At the Puertecitos mine the working-tunnel passes through a bed 30 feet wide that carries a large amount of chalcopyrite, with a little zinc and galena, the ore averaging about 15 per cent. copper. This bed is capped by a white marble, which, as shown elsewhere, is a relatively impervious rock. The ore consists, approximately, of:*

	Per cent.
Chalcopyrite, ...	25
Galena, ...	5
Calcite, ...	35
Actinolite, ...	20
Quartz, ...	15

The chalcopyrite and galena show an evident association with the dull green, finely fibrous actinolite. The sulphides occur in grains up to three-fourths of an inch across; they are not crystalline, but of irregular form and of compound structure (*i.e.*, not of uniform crystalline orientation). The actinolite and calcite occur in patches, but the quartz is idiomorphic, and the crystals penetrate both the minerals just mentioned. The ore, however, appears to cover and enclose the quartz.

Germany.—Richard Beck has described very fully a deposit of this structural type in his recent book, and I therefore insert a translation of his description in full :†

"1. The ore-deposits of the contact area of the granite of Berggiesshübel, in Saxony.

"The ore-deposits of Berggiesshübel, in the so-called Elbe Valley mountains of southeastern Saxony, represent a specially well-studied and typical example of contact metamorphic ore-occurrences, and for this reason will be here first described, and in some detail, although they have long since lost their economic importance.

"At Berggiesshübel, in the moderately uptilted schist rocks, several granite stocks appear, among which the one of Markersbach occupies the foremost place by its size and by the extent of its contact phenomena. Close to its western border lies the mine district of the old mining town of Berggiesshübel.

"The outcrops of the various beds of the Phyllite formation and the lower

* These figures are based upon estimates made by measurement of specimens and thin sections of the ore.

† *Lehre von den Erzlagerstätten*, Leipzig, 1901, p. 609.

Silurian formation are there distinctly seen terminating at the border of the granite, and various exposures and other evidences prove that the surface of the eruptive stock dips at a low angle under the schists thus traversed. The sedimentary rocks thus adjoining and, in part, overlying the granite have been subjected to strong contact metamorphosis.

"Turning specially to the Silurian formation, we find that the clay slates were changed into hornstone, horn schists and knot-schist, while the diabase tuffs,—the so-called Schalsteine,—were changed into various kinds of hornblende schists, especially actinolite schist, also banded salite-hornblende schist. The limestone layers, however, intercalated in the clay schists and especially in the tuffs, were turned into marble beds, or, in part, into salite-garnet rock, or, finally, into magnetic iron beds.

"These limestone strata may be followed from NW. to SE. in their strike, for long distances, in many good exposures, deep limestone quarries and natural outcrops, from Maxen across the villages of Biensdorf and Gersdorf, to the point where they enter into the contact-area of the granite. Over this whole distance, however, these limestones are devoid of ore, except a few quite insignificant beds of red and brown hematite, which occur in quite limited patches, for example, at Nenntmannsdorf, at the boundary between limestones and schists.

"In the contact-area, however, the calcium carbonate has been partly or entirely displaced from these beds, and replaced by secretions from immigrant silicate and ore-solutions, such as salite and garnet, as well as magnetite and various sulphide ores. The distribution of the marble, calcium silicates and ores within the beds is very remarkable and diverse, and throws a bright light on the manner of this replacement metamorphosis.

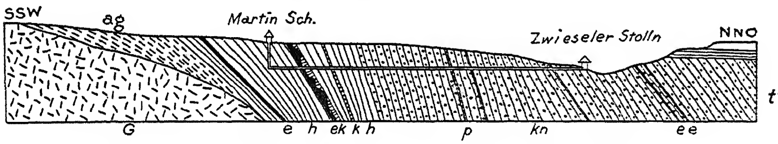
"First let us note that the marble still shows clearly the stratification of the originally dense Silurian limestone out of which it was formed. Even the alteration between thin limestone beds and diabase tuffs, which occurs not infrequently in the Silurian at that place, may repeatedly be observed in the contact-area between marble and hornblende schist, except that the limestone, wherever it formed thin streaks and layers, has for the most part been changed throughout into a light-green pyroxene rock.

"In the larger limestone layers in the contact-area one notices not infrequently a structure consisting of separate marble bands, separated by layers of salite-garnet rock, and also a thin-stratified alteration between garnet-rock and magnetic iron-ore. More usually, however, quite irregular nests and lumps of magnetic iron-ore lie in the midst of the marble, cutting across its stratification. In such cases they frequently penetrate into the marble with jagged or stringer-like projections. At some places, as, for example, in the limestone workings near the Hermann shaft, even irregularly vein-shaped masses of magnetic iron-ore were observed in the midst of the limestone. On the whole, the ore clings especially to the lower boundary of the marble bed, frequently swelling up from there, cutting with its upper boundary across the strata of the marble and entirely replacing it for long distances, in some places for a width of 5 m. Finally, the ore-bodies are at times traversed by ramified stringers of the garnet-rock, forming a network among themselves. It thus appears that the ore-mass was broken, but that the infiltration of the solutions furnishing the garnet continued after this mechanical disturbance. That phenomena of disruption took place during the contact metamorphosis, at the time of the transition of the dense limestone into marble, is furthermore indicated by the frequent stringers of coarsely foliated calcspar, which traverse the blackish marble as white bands. They seem to have been formed during the process itself, as primary stringers. Occasionally they carry some garnet.

"Other ores besides magnetic iron take part in the composition of the ore-beds of the locality, especially copper minerals, such as chalcopyrite, erubescite, copper glance, rarely gray copper-ore. From these have resulted a number of secondary copper-ores, malachite, etc. Less frequent admixtures are iron pyrites, arsenical pyrites, galena and zinc-blende.

"While the subsequent introduction of all these ores into the limestone beds of that locality is beyond question, doubts may still be entertained concerning the origin of the metalliferous solutions. Two theories may be advanced in regard to this point. One theory is, that the metallic compounds in question were originally finely distributed through the adjoining rock, especially in the diabase tuffs, and were only later concentrated through the contact metamorphosis, through redeposition in the limestone by means of mineralizing agents derived from the granite, after expulsion of the carbonic acid of the calcium carbonate. The other theory is that these metallic compounds were directly brought up with the granite from great depths, and were infiltrated into the adjoining rock in solution in the over-heated water accompanying the eruption. The latter theory has the greater probability, since all the hornblende schists and hornstones are rich in iron at the contact also,—much richer, in fact, than elsewhere, aside from the contact.

FIG. 1.



Section through the contact zone of Berggiesshübel, Saxony.

G = Markersbach granite; *ag* = andalusite-mica rock; *h* = hornblende and pyroxene-schists; *kn* = spotted schists; *e* = ore-bodies; *k* = crystalline limestone; *p* = quartz-porphyry; *t* = Sub-Turonian and Cenomanian.—R. Beck, *Erzlagerstätten*, p. 611.

"This is rendered still more probable by the fact that in the same district *ore-lodes* also exist in the granite, which are characterized by copper-ores, and, in part, traverse the ore-beds. They seem to represent the main channels of supply for the metallic solutions emanating from the granite.

"Finally, besides these copper-lodes, tin-bearing stringers are also known to occur in the metamorphic limestone-beds of that locality. These stringers consist of orthoclase, fluorspar, quartz and lithia-mica distributed in zones. Near them A. W. Stelzner also discovered tinstone, together with chalcopyrite and pyrite, as impregnations of certain strata of the beds, consisting mainly of chlorite.

"The Markersbach granite is thus seen to be surrounded by an aureole of highly diverse metallic compounds.

"The iron-mining industry of Berggiesshübel, formerly of some importance, is now practically extinct."

Gold-Deposits.

The recognition of telluride ores in contact-deposits is, I believe, new. It is expressly stated by Lindgren, as a result of his review of the literature on the subject and his own experi-

ence, that no tellurides occur in contact-deposits.* I have found several examples of this interesting type of deposit, which is clearly entitled to rank as a special class in metamorphic deposits. This at once brings up the question of permanence in depth of such deposits, discussed elsewhere in this paper.

Western Montana is a mountainous region in which there are several great areas of granitic rocks breaking up through sedimentary strata and earlier igneous rocks. Along the limestone contacts of these granitic intrusions (batholiths) ore-deposits are often encountered, though they are rarely of any great economic importance. Most commonly they are of the Kristiania type, examples of which may be found at Georgetown, Cable, and other localities west of Anaconda; in the Highland Range south of Butte; in the Indian Queen mine, on Birch Creek, in Beaverhead county; at Elkhorn, and at very many localities about the granitic borders mentioned. There are, however, examples of contact metamorphic deposits of the Cananea type at Elkhorn and Phillipsburg.

Bannack Type.—The placers of Grasshopper Creek, at Bannack, were the first great gold-placers discovered in Montana. Attention was soon attracted by the ledges on the slopes above the basin, in which the richest gravels occurred, and a "lode" excitement, almost as fierce as that of the placer-days, followed. Enormously rich ores were taken out, several mills were erected, and the ground was burrowed to a shallow depth wherever the pockets and streaks of rich ore occurred. Yet, despite the attractive prospects and good returns, the ore-deposits have never been explored in depth, the deepest shaft being about 300 feet deep.

The ore-deposits are typical contact metamorphic deposits. A central boss of diorite, about three-fourths of a mile in diameter, is surrounded by a series of upturned Paleozoic limestones and associated shaly rocks, dipping away from the granite on all sides at angles of 10° to 45°. This dome or anticline has been eroded, and the granite now forms the surface of the low central portion of a basin, whose surrounding heights are formed of limestones flanked by heavily-bedded

* "Character and Genesis of Certain Contact-Deposits," *Genesis of Ore-Deposits*, p. 717, under heading "Constituent Minerals;" also, *Trans.*, xxxi., 227.

quartzites of Carboniferous age. The diorite intrusion, though laccolithic in its general character, has a very uneven contact, breaking irregularly through the limestones, and holding included blocks of the latter within its mass, while tongues of the igneous rock project out and penetrate the adjacent sedimentary rock.

The limestones are highly altered about the contact; but, owing to the fact that the diorite comes in contact with limestones of varying composition, the resulting rocks differ greatly in mineral constituents. In the main, these contact rocks are either impure marbles or are composed of brown garnet, epidote, calcite, and other common contact metamorphic minerals. The ore-deposits, in part, follow the actual contact between diorite and contact rocks. Where limestones prevailed, the ore-bodies were irregular; tongues and chambers of ore extend out into the limestone, and the ore (now oxidized) consists of porous iron-stained quartz the cavities of which show the crystalline form and striations of coarsely crystalline gold-bearing pyrite. Where the garnet rocks prevail the ores do not follow the contact, except in a general way, but occur in the more garnetiferous bands which alternate with epidotic rocks and marbles and mark the alteration of beds of limestone of differing composition. The ore-minerals consist of telluride of gold, together with some free gold, disseminated and rather abundant specular iron, some pyrite and less chalcopyrite. As usual, the telluride ores are spotty, occurring in rich bunches, but there is also a general dissemination through the rock, and all the garnet-specular-iron rock contains a few dollars per ton in gold, as shown by a large number of assays.

Elkhorn.—The Elkhorn district is situated in central Montana, about half-way between Helena and Butte. The ore-deposits occur at the eastern border of the great granite area that covers the greater part of Jefferson county. At Elkhorn this granite cuts abruptly across the ends of tilted sedimentary beds embracing a great variety of rock types of different geologic ages. The granite is of Tertiary age, and later than the fragmental andesitic rocks which form the neighboring peaks and which rest upon the sediments. The principal ore-deposit, that of the Elkhorn mine, is not a contact metamorphic deposit, but a "saddle" deposit formed in

the axis of a steeply dipping fold, between an altered shale (hornstone) hanging-wall and a crystalline dolomite crushed along the fold. The sedimentary rocks near the igneous contacts are highly altered, and are good examples of contact metamorphic rocks. Iron ore-deposits on Elkhorn Peak are contact-deposits of the Kristiania type, and there are several true contact-deposits of pyrite of too low-grade to work.

A half mile northwest of the Elkhorn mine, on the western slope of a steep and wooded ridge composed of altered sedimentary rocks, lies the Dolcoath mine, a property as yet in the prospect stage. Shipments of sorted ore have been made, and the oxidized ore shows native gold flecking the rock. The ore is a bed of garnet-diopside rock (altered limestone) 15 to 18 inches thick, dipping at 55° to the east and carrying gold in bismuth sulphide (bismuthinite) and bismuth telluride (tetradymite). This ore stratum is conformable with the adjacent beds, but differs from them in composition. The rocks have been studied by Dr Barrell,* who determines their approximate composition to be as follows:

Ore Stratum.		Footwall.		Hanging-Wall.	
Diopside	45	Diopside	30	Augite	5
Garnet	40	Garnet	10	Biotite	25
Calcite	12	Basic feldspar	60	Basic feldspar	66
Sulphides, with gold	3			Sulphides, no gold	4
	100		100		100

Samples from the sacked ore of the upper levels yielded $156.00 per ton in gold, but average samples from the bottom level, made during an expert examination of the property by a Butte mining engineer, yielded but $4.50 per ton in gold.

Similkameen Type (*British Columbia*).—The Nickel Plate mine, which promises to be a great gold-producer, is situated near the Similkameen river, Osoyoos mining division, west of Penticton.† The ore consists of a garnet-calcite-epidote rock, whose mineralogical composition and geological occurrence both show that it is an altered impure limestone. The ore-mineral is arsenical pyrites, disseminated through this gangue

* *Op. cit.*, *Am. Jour. Sci.*, April, 1902, p. 295.

† *Report of the Minister of Mines of B. C.* for 1900, p. 883.

rock and concentrated in the high-grade ores, which occur in extraordinarily rich bands. Mr. H. V. Winchell informs me that the ore-body is of contact metamorphic type. The specimens which he collected show the arsenopyrite to be confined, almost exclusively, to the garnetiferous portion of the ore, the green (epidotic ?) portion being very low-grade.

So far as known, arsenopyrite has never before been found in contact-deposits. It has, however, been observed in certain pegmatitic veins which are believed by some observers to be of pneumatolytic origin.*

Changes in Rocks due to Contact Metamorphism.

General Effect.

It is a well-known fact that certain intruded igneous rocks have exercised a profound influence upon the wall-rocks confining and adjoining them, while other types of igneous magmas have produced only a slight effect. To a large degree this alteration, or contact metamorphism, is due, as has been shown by Iddings,† to the length of time the adjacent rocks have been heated. If the conduit of a volcano is broken through sedimentary rocks, and this conduit serves as a vent for a prolonged period of time, and is finally filled by magma that cools as a coarse-grained rock, it is evident that these conditions favor extreme metamorphism of the adjacent material. If a small sheet or dike breaks through sedimentary strata, and is promptly chilled, the magma exercises but little apparent influence upon the wall-rock. It is, therefore, largely a question of physics. The great intrusion takes a long time to cool; the magma crystallizes as a granular rock, and the adjacent rocks are heated for a long period. It is partly, therefore, a question of the mass of the magma cooling. Professor Kemp‡ has succinctly stated the known facts upon this subject in his recent paper upon the "Rôle of Igneous Rocks." On the other hand, although the result of such long-continued heating of

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* O. A. Derby, "Notes on Brazilian Gold-Ores," present volume, p. 282.

† "Electric Peak and Sepulchre Mountain," 12th *Ann. Rept. U. S. Geol. Survey*, Pt. I., pp. 569–664.

‡ *Genesis of Ore-Deposits*, p. 692; also, *Trans.*, xxxi., 180.

wall-rocks has been recognized by geologists for many years, the fact that different rocks show varying effects has been commonly imputed to the nature of the rock, and until recently there has been no lucid discussion of the effect of contact metamorphism upon sedimentary rocks. Quite recently there appeared a paper by Prof. Joseph Barrell, entitled "The Physical Effects of Contact Metamorphism."* In this paper it was shown that the metamorphism of sedimentary rocks by the heat of igneous masses is accompanied by the liberation of enormous volumes of gases, with attendant shrinkage of volume and the formation of vein-fissures and impregnation deposits. Several writers, particularly Vogt, Kemp, and Lindgren, have recently drawn attention to the metasomatic and impregnation effects of the mineralizing vapors coming from the cooling igneous magma and carrying dissolved metallic minerals along favorable channels in the contact zone. In addition to this eruptive after-action of Vogt, there is a more or less complete expulsion of carbon dioxide and combined water from the sedimentary rocks, accompanied by the formation of new minerals and the induration of the rocks. As is well known, the alteration of pure sedimentary rocks by contact metamorphism is as follows: Sandstone to quartzite; clay-stone, or shale, to hornstone; limestone to marble; but as, in nature, these pure rocks seldom exist, and it is the impure limestones, sandstones and shales which are most common, the alteration of such rocks produces a more or less striking metamorphism—the material recrystallizing as garnet, wollastonite, epidote, etc.

Changes in Mass, Volume, and Mineral Composition.

As the chemical elements remain the same in the altered as in the unaltered rocks, save for the greater or less expulsion of water and carbon dioxide, it is possible to tabulate the mineralogic changes. This has been done by Professor Barrell, and from his table it is possible to work out not only the original composition of the unaltered sediment, but the changes in mass and volume which have taken place in the process of metamorphism.

The greatest changes in volume are due to escaping gases

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* *Am. Jour. Sci.*, vol. xiii., April, 1902, p. 279.

and vapors. His conclusion that metasomatic additions during this metamorphism are prevented by the internal pressure of the escaping gases is not regarded as correct for all cases, though it is based upon the belief that by the time the pressure is relieved sufficiently to permit the ingress of heated waters or mineralizing vapors from the adjacent magma the rock is recrystallized; also, as a result of the hydrostatic pressure of the still liquid magma, it is usually dense. While it may be true, as stated by Barrell, that metasomatic infiltration of the metamorphic strata does not *usually* take place, yet instances have come within the observation of the writer where such action is very pronounced. Differential shrinkage has given the strata the porosity of a burned brick, and, as aptly noted by Barrell, the analogy is the more appropriate since in these cases the action is one of thermal metamorphism, without sufficient pressure to result in a close texture. Two instances are given by Barrell, both in the Elkhorn region of Montana, one already quoted. The conditions in the region are particularly favorable for a study of the varying effects of the thermal metamorphism caused by the intrusion of a large igneous mass into sediments of widely varying composition. The granite mass cuts across tilted strata whose inclination favors alteration, and whose wide variety of composition results in striking differences in the porosity of the altered rock. Inasmuch as the altered sediments are on top of the granite, they have not been subjected to the same pressure that would have changed them if they had been part of the rock enclosing the intrusion. Moreover, the pressure would be transmitted by the denser layers, and would not be transverse to the borders.

A consideration of the physical conditions involved shows that in many instances the porosity induced by thermal metamorphism of rocks forming the side-walls of igneous intrusions is probably counteracted by the hydrostatic pressure of the magmas. It has been found that metamorphism of the sedimentary rocks would be practically completed before solidification of the magma begins,* and completed while the magma was able to act hydrostatically and transmit lateral pressure.

* Barrell, *op. cit.*, p. 294.

Under these conditions the shrinkage of the vertical walls would be largely lateral, and result in a corresponding lateral expansion and a *vertical subsidence* of the magma. Where, however, as is so commonly the case, great masses of granite are capped by relatively thin layers of altered sediments, as, for example, in the region about Helena, Montana, the sediments above the magma, though subjected to pressure, would transmit this pressure along the heavier and more competent beds; while the intervening, weaker members would retain the porosity due to recrystallization and escape of gases, except, of course, at the immediate contact with the magma. It is evident that in such cases the porosity of the strata near the igneous inclusion favors the escape of pneumatolytic gases along and through the porous strata.

Genesis of Contact Metamorphic Deposits.

Cause of Contact Metamorphism.

That contact metamorphism is due to intrusive masses of molten magma is now generally accepted. The usual theory advanced is that the heat of the magma, together with the watery vapors given off by it, have caused the metamorphism. This is the explanation advanced by both Lindgren and Vogt. The latter has quoted the Swedish physicist, Arrhenius, as showing that the physical and chemical action of watery vapors upon a magma prove such vapors to be competent to extract the heavy metals from the magma. Barrell, however, has shown that the intrusion of magma heats the adjacent sedimentary rocks to very high temperatures, generating enormous volumes of gas and watery vapor by changes caused in the nature of the sedimentary rocks, and, moreover, that the process of recrystallization is complete before the magma cools. This latter conclusion, reached from a study of the physico-chemical actions involved, is confirmed by the field-evidence at Elkhorn, Mont., where tongues and dikes of the igneous rock penetrate the contact rocks, and accounts for similar dikes which at Boundary Creek, B. C., cut the *contact ore-bodies*. It is, therefore, not necessary to assume that watery vapor from the *cooling igneous mass* has played the only part in the metamorphism.

Whether we do or do not accept this statement as completely

proven, it must be admitted that the effect of the igneous magma upon its confining walls is not limited to this first metamorphism of the sedimentary rock. The molten magma gives off vapors,—pneumatolytic vapors they have been called,—and that these escape into the adjacent rocks we have abundant evidence. As some geologists appear to question our knowledge concerning this action, it may be well to summarize the known facts concerning the gaseous emanations of igneous rocks. At present our knowledge of these is derived from (1) analyses of the gaseous emanations of volcanoes and lava-flows; (2) analyses of the gases occluded in cold rocks; (3) analyses of the sublimation-products formed by fumaroles; and (4) evidence of contact metamorphism of included masses of sediments entirely surrounded by the igneous rock.

Concerning the first of these proofs, there is considerable direct positive evidence furnished by competent observers and chemists. This has been summarized by Geikie,* who states that hydrochloric acid is evolved in abundance from the clefts at Vesuvius; also vast quantities of free hydrogen or combustible compounds of this gas are given off from Vesuvius, and were distinctly recognized by Fouqué in the eruptions of Santorin.† These gases, when studied spectroscopically, were found to contain traces of chlorine, soda and copper. Analyses, by Fouqué, of the gaseous emanations were found to contain abundant free oxygen, as well as hydrogen, and one analysis gave the results in column I.:

	I.	II.
Carbon dioxide,	0.22	15.38
Oxygen,	21.11	13.67
Nitrogen,	21.90	54.94
Hydrogen,	56.70	8.12
Marsh gas (methane),	.07	5.46
Argon,	......	0.71

In column II. is given the analysis by Moissan of the gas collected by Lacroix from a fumarole on the Rivière Blanche, Martinique, whose temperature was high enough to melt lead rapidly, but not zinc (*i.e.*, about 400° C.). An abundance of sulphur and ammonium chloride was deposited about it.‡

Fouqué infers§ that the water vapor of volcanic vents may

* *Manual of Geology*, p. 188.

† *Santorin et ses Eruptions*, p. 225.

‡ *Comptes Rendus*, cxxxv. 1085, 1902.

§ *Santorin et ses Eruptions*, p. 225.

exist in a state of disassociation from the molten magma when lavas rise. Fluorine and iodine have likewise been observed.

In a recent lecture, Prof. Eduard Suess* has directed attention to the gaseous emanations of volcanoes, and indicated their part in the formation of mineral veins. After describing his own observations at Vesuvius, he says:

"Turning now to the gases accompanying the eruptions. After steam, chlorine and gases containing sulphur are the most important, and carbonic acid gas comes next. Their occurrence follows a definite law. So far as it has been possible to approach them, all fumaroles actually within vents contain steam; but the hottest fumaroles (over 500° C.) on the surface of cooling lava-streams, where approach is easier, are dry. In the emanations from these high-temperature fumaroles are found chlorine compounds, and along with them fluorine, boron and phosphorus,—substances which are the first to disappear as the temperature of the fumarole sinks. Sulphur persists longer, often combined with arsenic. Carbonic acid is given off freely till a much later stage, sometimes till the fumarole is comparatively cool, notwithstanding that it is observed in the hottest dry fumaroles. Fumaroles in different 'phases of emanation' may occur quite near one another. The steam of the volcano cannot be derived from vadous infiltration; for, if it is, whence the carbonic acid? Both must come from the deeper regions of the earth; they are the outward sign of the process of giving off gases which began when the earth first solidified, and which to-day, although restricted to certain points and lines, has not yet come to a final end. It is in this manner that the oceans and the whole vadous hydrosphere have been separated from the solid crust. Volcanoes are not fed by infiltration of the sea, but the waters of the sea are increased by every eruption."

Concerning the analyses of the gases occluded in the cold rocks, the evidence is not so satisfactory. From the study of microscopic slides it is well known that gaseous and watery inclusions occur in crystalline rocks, and various attempts have been made by chemists to estimate the quantity of included vapor so held. Recently, Dr. M. W. Travers, in a paper on the "Origin of Gases Evolved on Heating Mineral Substances, Meteorites, etc.," has shown "that in the majority of cases

* *Geographical Journal*, London, vol. xx., p. 520, November, 1902.

where a mineral substance evolves gas under the influence of heat, the gas is the product of the decomposition or interaction of its non-gaseous constituents at the moment of the experiment."*

Notwithstanding this fact, however, we have abundant evidence, in the analyses of obsidian and pitchstone, of the presence of a considerable proportion of water; and it is well known that these rocks change into pumice on heating. Also the presence of fluorite in the dense and almost glassy phonolites of Montana is to be remarked here. The Hawaiian Island lavas, though highly vesicular, contain practically no water, and Whitman Cross† has noted the absence of steam from the lava cauldron of Kilauea, although there was an abundance of sulphurous vapors and brown vapors of an unknown composition given off from clefts immediately adjacent to the lava lake.

Attention might also be directed to the recent work of Armand Gautier,‡ in which he shows that granite and other crystalline rocks evolve large quantities of vapors when heated.

Third, the analyses of the sublimation products found about fumaroles show conclusively that metallic salts, as well as non-metallic, are given off by the igneous emanations, or result from reactions between the escaping vapors and the solids with which they come in contact. Besides sulphur, chlorides of sodium, potassium, iron, copper and lead also occur, and specular iron, oxide of copper and iron chloride have been observed by Geikie and Fouqué.§

Fourth, the evidence of contact metamorphism, as studied in included masses, affords direct proof of the action of pneumatolytic vapors when the original composition of the included mass can be known with any certainty. Under such conditions one can exclude the reactions indicated in the case of the confining walls of the magma, and there is no doubt that in many cases there is a direct migration of material, particularly silicates, also fluorine and chlorine, together with copper sulphide and iron oxide, into the included masses. Such masses have been studied by Lindgren|| at the Seven Devils district of

* *Proc. Royal Soc.*, vol. lxiv., p. 142. (Read Nov. 24, 1898.)

† Verbal communication.

‡ *Zeit. Prak. Geol.*, vol. ix., p. 383, 1901. § Geikie, *Manual of Geology*, p. 188.

|| "Character and Genesis of Certain Contact-Deposits," *Genesis of Ore-Deposits*, p. 722; also, *Trans.*, xxxi., 232.

Idaho, and by Kemp in the San José district, and Tamaulipas, Mexico.

Inasmuch as included fragments of pure limestone are changed to garnet-rock and impregnated with metallic sulphides, vesuvianite, axinite, etc., whose constituents are not normal to any of the original rocks surrounding the intrusion, the evidence is satisfactory that there was a migration of material in the form of vapor from the igneous magma into the adjacent rocks.

From this evidence we are justified in assuming that there is a series of "eruptive after-effects," as Vogt has called them, which start at the moment of the intrusion and continue until the rocks have completely cooled, and which grade one into the other.

On the other hand, if the resulting metamorphic rocks are porous, as in certain cases we know them to be, the vapors from the cooling magma will be "blown in" (to use Vogt's term), and ore-deposits may be formed in this way.

Professor Suess, in the lecture already quoted, has called renewed attention to the fact that mineral veins are to be regarded as the result of waning phases of volcanic (igneous) phenomena. "Hot springs may be taken as the latest phase of a whole series which led up to the present deposits of ore." His whole paper is an argument against the theory that either the majority of ore-deposits or of hot springs are of meteoric derivation.

That gaseous emanations rising through fissures toward the earth's surface can mingle with ordinary meteoric ground-water must be admitted, and it is believed that much of the discussion between those who advocate the deposition of ores by circulating ground-waters, deriving their metallic contents from the generally cold rocks traversed in their course from the earth's surface downward and back again to the surface, has arisen because of the failure to recognize that in this mingling of igneous emanations and ground-waters we have the true explanation. The ground-waters alone, either cold or heated, would not ordinarily take up enough material from the rocks traversed by them to enable the waters to deposit ores in veins. On the contrary, it is the gaseous emanations carried by the ground-waters into trunk-channels that deposit ores by reaction with other currents, wall-rock, etc.

Contact metamorphic deposits, properly so-called, occur as a result of the metamorphism of sedimentary rocks by igneous intrusions. The definition thus excludes all deposits formed along ordinary contacts, due solely to circulating waters, even where such waters contain substances derived from igneous emanations dissolved in the waters,—as, for example, the Mercur, Utah, and Judith Mountain, Montana, deposits, and other ore-bodies of similar character. When the ore-minerals are intergrown with the garnet-epidote and other gangue minerals, the deposits are clearly pneumatolytic.* Another class is the result of later impregnation by igneous emanations penetrating a porous stratum, the stratum itself made porous as a result of metamorphism. A third class are the result of the precipitation of copper or other sulphides from ascending alkaline solutions, supposedly hot waters, by the lean sulphides formed by pneumatolytic action (deposits of the second class). In the first class the ores are of simultaneous origin with the gangue minerals which are admittedly due to contact metamorphism. In the second class, ores were introduced subsequent to the metamorphism of the rock (Elkhorn type). The third is probably difficult to distinguish from the first, but is believed to exist at Cananea, Mexico, though not the kind designated by that name.

Barrell has calculated the changes taking place in two examples at Elkhorn. The first is a thin band of hornstone occurring in marble and consisting of 50 per cent. of diopside, with 46 per cent. of feldspar and 2 per cent. each of quartz and fluorite. It is evident that the crystallization of diopside and feldspar left the stratum very porous, and that the pores were filled by quartz and fluorite from pneumatolytic vapors.

The second instance given by him is the ore-stratum of the Dolcoath mine, already described. This is a typical instance of a porous layer.

"It is seen that even if all the calcite of the ore-bearing stratum be regarded as a primary mineral, the shrinkage in the ore-stratum has been somewhat greater than in either the foot- or hanging-wall, since the feldspars and biotite are minerals which, as shown by the alkalies present, were formed from sediments not fully hydrated or carbonated. Moreover, a microscopic examination of the ore-stratum shows parallel sinuous cracks due to tension, and not to shear, and now filled with calcite. Elsewhere in the section the calcite exists as a sponge, holding garnet, diopside, and ore-grains within it, and its secondary nature is not so

* *I.e.*, formed by the action of gases or vapors at high temperatures and pressures reacting upon solid materials.

clear. The ore is associated with the calcite, and also with a certain coarser crystallization of the diopside."*

Professor Barrell calculates the shrinkage of the ore-stratum at 40 per cent., of the hanging-wall at 15 per cent., and the footwall at 25 per cent., so that it is evident that we have here a steeply inclined pervious stratum capped by a relatively dense impervious bed, and offering a favorable channel for uprising vapors, given off by the cooling magma beneath, or for circulating waters.

The source of the metallic mineral deposited in these contact-rocks, if not positively known, is commonly assigned to the solfataric vapor given off by the cooling igneous magmas. There has always been more or less skepticism concerning the source of the oxide of iron, magnetite and specularite, which are such common and characteristic features of true contact-deposits. Inasmuch as the disassociation of the interstitial water of the sedimentary rocks by the intrusion of highly-heated magma would provide a sufficient supply of oxygen, the occurrence of such ores, produced by reaction with the iron-compounds present, would be explained, while the fact that such deposits are almost entirely confined to the immediate vicinity of the igneous contact can be readily understood.

Permanence in Depth of Ore-Deposits of this Class.

So far as development and experience show, the deposits of the Kristiania type occurring at actual contacts are very bunchy, and cease in depth; a notable example being the Seven Devils, Idaho, deposits. In the Cananea, Mexico, example, and the Boundary, British Columbia, deposits, the copper-ore is more uniformly distributed, and there seems no theoretical reason why the primary sulphide-ore should not continue of unchanged tenor in depth down to the igneous contact. In the case of the gold-ores, both tellurides and arsenopyrite, so little is known that no prognosis can be made. The deepest workings at Bannack are but 300 feet below the surface. At Cripple Creek, where the deposits are not of contact-metamorphic origin, though they are considered to result from volcanic emanations, the values decreased with depth. However, recent discoveries indicate workable bodies of auriferous gray copper at greater depths. The Cornwall tin- and copper-veins are

* *Op. cit.*, pp. 295, 296.

now practically worked out. At the Dolcoath the ore is low-grade at 150 feet. If the theory of genesis be true, there is no reason now known for the impoverishment of contact metamorphic deposits in depth.

Mineral Veins near Igneous Contacts.

In addition to the pneumatolytic deposits on igneous contacts and those in altered strata near the contacts, there are many productive mines working true veins cutting the igneous rock and the contact-rocks above them. Such vein-fissures are caused both by the contraction due to the crystallization and cooling of the igneous rock and by the shrinkage of the metamorphic zone above the igneous rock. Examples of this type have already been mentioned. As shown by Pirsson,* the radial fissures which form so remarkable a feature of certain igneous centers are not due to the initial expanding force of the intruded magma, but to the contraction-cracks. The vast amount of heat given off by the cooling magma effects a considerable expansion of the surrounding rocks. As the magma and its surrounding shell of heated sediments cools down it must contract, and this contraction will result in a cracking both of the igneous rock and the contact-zone; and, if the rocks of the contact-zone are homogeneous, the cracks will assume a more or less radial position. If these cracks extend to a depth sufficient to reach still molten magma, they will be filled, and dikes will be formed; if not, the cracks become channels for pneumatolytic vapors and later circulating waters, and thus pegmatite veins and true mineral veins may be formed, and may merge into one another. It is possible that the (now brecciated) Granite Mountain vein at Phillipsburg, and the very productive veins at Marysville, Montana, may have originated in this manner. But, in addition to radial cracks, the shrinkage would also tend to produce cracks parallel to the borders of the intrusion,†—a phenomenon observed in casting, and also in the cooling of lava-sheets,—as, for example, those of Obsidian Cliff, in the Yellowstone Park region, a discussion of which has been given by Iddings.‡ As circulating solutions travers-

* "Complementary Rocks and Radial Dikes," *Amer. Jour. Sci.*, vol. l., 1895, p. 116.

† For ore-deposits of this type, see Beck, *op. cit.*, p. 182, Fig. 119.

‡ *7th Ann. Rept., U. S. Geol. Surv.*, for 1885-6, pp. 249–295.

ing contact-zones would course through the more basic differentiated part of the magma, which is well known to be richer in metals than the normal magma, there has been a combination of conditions favoring ore-formation, and it is easy to see why such ore-deposits occur in or near the contacts of great igneous masses.

I hold that the metallic contents of such veins are not gathered by ordinary meteoric water, as maintained by Van Hise. The water-content of the sedimentary rocks (ground-water) present at the time of eruption was expelled by contact metamorphism. The ore-forming solutions were in part of direct igneous origin;* these primitive hot vapors and waters rise and penetrate the zone of circulating meteoric waters, heating the latter and charging them with both metallic salts and with fluorine, chlorine, boron and other active mineralizers. The resulting mixture of plutonic and meteoric waters is a much more energetic solvent than normal ground-water, and is capable of adding metallic salts extracted from the rocks traversed by the waters to the original material derived from the igneous emanations.

Conclusions.

Contact metamorphic ore-deposits occur about the margin of intrusive masses of granular igneous rock, either at the actual contact or in the zone of metamorphosed sedimentaries. The deposits of economic value occur only where strata or blocks of impure limestone have been crystallized as garnetiferous or actinolite-calcite rocks, with consequent porosity. The ore-minerals are intimately associated with these aluminous silicates, and may be either intergrown, or metasomatic replacements, or the result of interstitial filling with partial replacement. The conversion to garnet-epidote-calcite, etc., rock was complete before the consolidation of the igneous rock. The ore-minerals were introduced in gases and vapors—solfataric emanations—from the eruptive masses of which they constitute pneumatolytic after-actions, or by hot circulating primitive waters given off by the cooling igneous mass. This theory of the genesis being true, the deposits should extend downward in depth to the granular rock.

* *I.e.*, primitive or igneogenous. The geyser waters of Iceland, New Zealand and the Yellowstone regions are probably mainly of this character, as maintained by Suess.

Ore-Deposition and Vein-Enrichment by Ascending Hot Waters.

BY WALTER HARVEY WEED, WASHINGTON, D. C.

(New Haven Meeting, October, 1902.)

THE enrichment of mineral-veins as a result of the migration of material from an upper oxidized or disintegrated part of a vein to a lower level, where it is redeposited, is now, I believe, quite generally accepted as one explanation of the occurrence of bonanzas in gold- and silver-veins, as well as that of bodies of high-grade ores in cupriferous deposits.* Vogt has called attention† to the fact that there are numerous examples of such rich shoots which are "of exclusively primary character, and dependent upon the laws which governed the original ore-deposition." To this I would add that there are also other examples which are neither of primary origin nor due to descending waters, but result from a reopening of the veins and their penetration by ascending heated waters whose metallic contents are deposited by reaction with the primary pyrite (and possibly other minerals), forming "secondary" enrichments.

My studies of the copper-veins of Butte, Montana, show: That the veins there are of several ages and systems; that the older primary quartz-pyrite veins were reopened by later movements, correlated with a period of volcanic activity; and that they were penetrated by hot alkaline waters carrying copper and arsenic in solution, which was deposited presumably by reaction with the pyrite of the original vein.

The enormous development of the Butte deposits, attendant upon the extraction of nearly 10,000 tons of ore a day, has revealed many facts concerning the nature and distribution of the ores. Enargite, the copper sulpharsenate, formerly a relatively rare mineral, is now found to be the chief ore of some veins,

* Weed, "Enrichment of Mineral-Veins by Later Metallic Sulphides," *Geol. Soc. Am. Bull.*, vol. xi., pp. 179–206.

† "Problems in the Geology of Ore-Deposits," *Genesis of Ore-Deposits*, p. 679; also, *Trans.*, xxxi., p. 168.

and to constitute a large part of the high-grade ore of the eastern properties. Its distribution is peculiar, and its significance can only be understood as a result of detailed study, but several facts stand out prominently, viz.: It occurs in immense ore-bodies, connected with faults, extending from the oxidation zone to unknown depths in some veins. But, in most cases, it first appears in deep-level workings. This ore was recently found in the 2000-ft. and 2200-ft. level of several mines; it is clearly younger than the pyritic ores, but older than the great glance ore-bodies, and is formed in small quantity in later fault-veins.

In the discussion of the genesis of the Butte deposits with the late Clarence King, he at first combated the principle of secondary enrichment, and adduced the presence of enargite as a conclusive argument against it. The later discovery of masses of brecciated enargite cemented by glance proves the enargite to be of earlier formation; and though the pyrite is the only possible source of the copper and arsenic in the original vein, numerous assays showed almost total absence of arsenic from these ores. In brief, all the evidence showed that enargite, though not a "primary" vein-mineral of the original vein, did not come from descending solutions, but must have come from below.

The bonanza-ore of Neihart, Montana, has been described by me as an example of secondary enrichment by descending waters. In the light of a riper experience and the experimental work of Dr. Stokes, it appears possible that the pearceite (arsenical polybasite) ores result from uprising alkaline solutions, though later descending solutions, carrying material derived from the oxidation of the ores, have to some extent complicated the situation. At any rate, it is difficult to account for the large amounts of arsenic necessary for the formation of these ores by the oxidation of very large amounts of primary pyrite almost devoid of this element; and it is known that arsenic occurs elsewhere in hot-spring waters, as at La Bourboule, France,* and in the Yellowstone Park.†

* Hague, "Notes on the Deposition of Scorodite," *Am. Jour. Sci.*, xxxiv., 3d ser., Sept., 1887, p. 171.

† Weed and Pirsson, "Sulphur, Orpiment and Realgar in the Yellowstone Park," *Am. Jour. Sci.*, xlii., p. 401, 1895.

Gooch and Whitfield, "Waters of the Yellowstone," *Bull.* 47, *U. S. Geol. Surv.*, p. 44 *et seq.*, 1888.

Recent experiments made in the U. S. Geological Survey Laboratory, by Dr. H. N. Stokes, show that metallic sulphides are reduced and precipitated from alkaline solutions of the general character of hot-spring waters by *pyrite*. The metallic substances may be assumed to be present as oxides of zinc, copper, lead, etc. The reaction with the alkaline waters alone is represented by the equation:

$$8\,FeS_2 + 15\,Na_2CO_3 = 4\,Fe_2O_3 + 14\,Na_2S + Na_2S_2O_3 + 15\,CO_2.$$

In the presence of a metallic oxide reacting with Na_2S, *e.g.*, ZnO, PbO, etc., the equilibrium will not be reached short of total decomposition of FeS_2, and we get

$$8\,FeS_2 + 14\,ZnCO_3 + Na_2CO_3 = 14\,ZnS + 4\,Fe_2O_3 + Na_2S_2O_3 + 15\,CO_2.$$

These are the only products present, and the reaction is complete with excess of $ZnCO_3$. The formation of Fe_2O_3 by action of a metallic salt on FeS_2 and the formation of thiosulphate have not been previously known. The latter was proved beyond question by qualitative and quantitative methods, and there is no evidence of the formation of sulphites. Pyrite and marcasite, with CuO in bicarbonate solution, react as follows:

$$2\,FeS_2 + 6\,CuCO_3 + 2\,KHCO_3 = 3\,Cu_2S + Fe_2O_3 + K_2SO_4 + 8\,CO_2 + H_2O.$$

Experiments with both pyrite and marcasite at 200° C. show that the theoretical amount of sulphuric acid is actually formed.

That such waters actually occur in nature is not absolutely known. The Yellowstone Park waters are, however, nearly of this character, and several springs at the Norris Geyser Basin are actually depositing the red and yellow sulphide of arsenic, and one case auriferous pyrite.* The Boulder hot springs, where mineral-veins are now in process of formation, in which small amounts of copper, gold and silver are deposited, are dilute solutions of alkaline waters.†

From my study of the waters and veins of the last-named

* Weed and Pirsson, *Am. Jour. Sci.*, xlii., p. 401, 1895.

† Weed, "Mineral-Vein Formation at Boulder Hot Springs, Montana," 21st *Ann. Rept., U. S. Geol. Surv.*, Part II., p. 233, 1900.

locality, I am led to the following theory of primary ore-deposition:

Theory of Ore-Deposition by Thermal Springs.

Recent researches have demonstrated that openings cannot exist in the rocks which compose the outer crust of the earth at depths of 30,000 feet or more, and that, indeed, under certain conditions, they cannot exist at depths very much less than that. Observations made upon deeply buried rocks, brought to the surface by uplift and erosion, are in perfect accord with these deductions, and prove that the "unknown depths" from which ore-deposits in waters are derived cannot exceed these figures. Assuming this to be true, it will probably be admitted (since heat and pressure facilitate solution), that hot waters circulating at considerable depths will dissolve and take into solution the various materials with which they come in contact. The capacity of hot water to contain such substances in solution will depend upon heat and pressure. The water will take up the less readily soluble salts only while the conditions are favorable. With less heat and pressure the solution may become saturated for any one substance, and, though still holding it in solution, be incapable of taking up any more of that substance. In this unstable condition a slightly lessened pressure and heat would bring about precipitation.

For this discussion it does not matter whether the hot waters are of igneous, or of original meteoric origin, since they are admittedly *hot* and traverse the deep-seated rock.

In an ideal hot spring, the circulating waters slowly traversing heated, but solid, igneous rocks, out of which they dissolve various substances, flow toward the point of easiest escape, which is the hot-spring fissure. For convenience, we will assume this fissure to be straight, one thousand or two thousand feet deep, and the waters to move upward very slowly. In its lower part, as in the pores of the adjacent rocks, heat and pressure are very great and the waters are not saturated, even for the most insoluble substances, and no minerals are deposited. Nearer the surface diminished heat and pressure make the water incapable of taking more of the less soluble materials in solution, forming what may be conveniently called the zone of saturation. Some salts, like alkaline sulphates, etc., are extremely soluble, and the point of saturation is scarcely ever reached in

nature, even at the earth's surface. Others, like silica, may be present in such amount as to saturate the water, but the solution is clear until cooling and relief of pressure cause supersaturation, and precipitation occurs; an example of this was seen at the Opal and the Coral Springs of the Norris Geyser Basin, in the Yellowstone Park. Still higher in the hypothetical hot-spring pipe, diminished heat and pressure cause the separation of the less soluble constituents, and for such materials this part of the tube is the zone of precipitation. It is well known that the metallic sulphides are soluble in alkaline solutions under heat and pressure, but examples showing their deposition by living hot springs are extremely rare. The more soluble substances will be carried farther upward before precipitation, and one might even suppose, if the solubilities of the substances were sufficiently unlike, that zones would be formed, each one of which consisted mainly of the particular substance thrown out by the change of pressure. This would produce an orderly distribution of the ores in a vertical direction. This, indeed, has been observed frequently. Chamberlin records it for the lead- and zinc-deposits of Wisconsin, and Rickard* for those of Colorado and elsewhere. In the writer's own experience the order appears to be galena on top, passing into highly zinciferous ores below, and this into low-grade pyrite.† It is a common experience to find this association in silver-lead deposits in limestone. This would account, also, for impoverishment in depth and the passing into the ever-present and readily deposited silica.

The conditions in a hot-spring tube are admittedly those postulated, *i.e.*, lessening heat and pressure as the surface is approached; the assumptions made are natural ones. This, then, would explain why hot springs do not deposit metallic sulphides at the earth's surface. Owing to their relative insolubility these are deposited (if present in the water) at depths below the surface. The Sulphur Bank quicksilver mines of California are examples. At the surface they showed only

* T. A. Rickard, *Trans. Inst. Min. and Metal.*, London, vol. vi., 1899, p. 196.

† Weed and Pirsson, "Castle Mountain Mining District, Montana," *Bull.* 139, *U. S. Geol. Surv.*, 1896. Also abstract in *Jour. Geol.*, vol. v., p. 210, 1897.

Weed, "Geology of the Little Belt Mountains, Montana," *20th Ann. Rept.*, *U. S. Geol. Surv.*, Pt. III., pp. 271–461, 1901.

sulphur and no quicksilver. In depth, quicksilver-ores appeared. Were these springs to die out and degradation to remove the upper 200 feet of the ground, quicksilver-veins would be exposed. It is probable that somewhat analogous conditions may exist at many hot-spring localities, and that if we could expose the lower part of the conduit we should find ore-deposits. This is the theory which the writer at present holds as to the genesis of the silver-gold-veins of Lump Gulch and other mining districts of Jefferson county, Montana, and which he believes is a rational ascension theory. All secondary alterations are here excluded, these remarks applying only to the primary vein-filling. It is lateral secretion only in the very special and limited application of that term to the leaching of relatively deep-seated rocks, and the gathering of such waters in a hot-spring conduit.

The close resemblance in nature and occurrence of these Boulder hot-spring veins to the jasper reefs of Clancy, Lump Gulch and many other mining districts in the granite area of Jefferson county, Montana, has already been stated. It may be accepted as certain that they also owe their origin to hot springs, and that the ore-deposits of such veins were formed by hot waters.

Theory of Enrichment.

Applying these conclusions to the question of vein-enrichments, it is first necessary to recall that bonanzas and rich ore-shoots are very frequently associated with brecciation and recementation of the vein-filling. Where the evidence precludes "secondary" enrichment from above, the possibility of enrichment by a new or renewed supply of hot water coming up the newly-formed fracture must be considered. The successive reopening of veins was formerly an accepted explanation of an orderly sequence of mineral crusts, implying a repeated uniform reopening. Such exceptional cases may occur, but it is certain that many veins occupy fissures that are lines of weakness in successive periods of earth movement. Even in the deposits still forming at Boulder Hot Springs, Montana, the veins have been fractured and the fragments cemented by newly deposited silica. At Butte and Neihart the veins have been broken by post-mineral fractures with later deposition of rich ores. The evidence at Butte (furnished by rock-walls, de-

posited ore and structural conditions) shows that the primary quartz-pyrite veins were broken by fissures that became the conduit for ascending hot alkaline waters. Such waters would tend to deposit any burden of metallic salts in zones as already outlined; they would also be influenced by the existence of the crushed pyrite of earlier deposition, which is an energetic reducing-agent.*

Dr. H. N. Stokes has continued his painstaking experimental work on the action of pyrite and marcasite, and the bearings of his results upon the chemistry of ore-deposition are of very great importance. It is well known that almost all hot-spring waters contain alkaline carbonates in solution. In an unpublished abstract of his report, which I have his permission to quote, he says:

"*Behavior of Pyrite with Carbonate or Bicarbonate Solution.*

"The reaction is as follows in case of either pyrite or marcasite and Na_2CO_3 or $KHCO_3$, at 100° or 190°:

"$8\ FeS_2 + 15\ Na_2CO_3 = 4\ Fe_2O_3 + 14\ Na_2S + Na_2S_2O_3 + 15\ CO_2$.

"The reaction is reversible, as far as the sulphide is concerned, and is more complicated than represented, because some alkaline polysulphide is formed. Being reversible, it is not possible to prove satisfactorily the presence of Fe_2O_3 in the solid residue, but the solution was shown to contain Na_2S, Na_2S_x and $Na_2S_2O_3$.

"If, however, the sulphide be removed as fast as formed, the reaction proceeds to an end, giving, finally, only Fe_2O_3, while the thiosulphate accumulates in the solution. This can be accomplished in several ways:

"(a) A circulating alkaline solution, carrying away the sulphur as sulphide and thiosulphate, would leave the pyrite or marcasite ultimately as Fe_2O_3 or its hydrate. This can hardly be effected in the laboratory on account of experimental difficulties.

"(b) The addition of a metallic salt capable of precipitating the sulphide as fast as formed allows the reaction to proceed to an end. This is what occurs in the above reaction with lead and zinc:

"$8\ FeS_2 + 14\ PbCO_3 + Na_2CO_3 = 14\ PbS + 4\ Fe_2O_3 + Na_2S_2O_3 + 15\ CO_2$,

and also with copper and silver (modified by the further conversion of thiosulphate into sulphide and sulphate):

"$8\ FeS_2 + 14\ Ag_2CO_3 + Na_2CO_3 = 14\ Ag_2S + 4Fe_2O_3 + Na_2SO_4 + 15\ CO_2$.

"(c) Since CO_2 partially decomposes soluble sulphides, we actually have a portion of free H_2S, which may be volatilized, thus enabling the reaction to proceed to an end. By heating FeS_2 with $KHCO_3$-solution in a sealed vessel filled with CO_2, and so arranged that the volatilized H_2S is continually taken up by an ab-

* H. N. Stokes, "Pyrite and Marcasite," *Bull.* 186, *U. S. Geol. Surv.*

sorbent, it was found possible to convert FeS_2 completely into hematite, without direct contact with metallic salts and in absence of oxygen. The same experiment was made with artificial amorphous Fe_2S_3, which can be converted into Fe_2O_3 by long boiling with water, H_2S escaping.

"It would seem from the above :

"1. That the conversion of FeS_2 into Fe_2O_3 is not a necessary proof of the action of oxidizing (descending) waters, but may be due to any alkaline solution free from oxygen.

"2. The circulating solutions which have acted on FeS_2 may carry away alkaline sulphide, and cause the deposition of other sulphides, as of copper, zinc, lead, silver, at another place."

These reactions apply to enrichment produced by ascending alkaline waters, such as those characteristic of the Yellowstone Park, Boulder Hot Springs, and many of the hot springs of the Rocky Mountain region.

If the hot ascending waters were *acid*, a different set of reactions, determined by Dr. Stokes' work, explain the solution of gold, silver and copper from minerals of the original vein-filling, and their deposition at a higher level on cooling.* The reaction is possible with a neutral solution, but not an alkaline one.

Conclusions.

1. Ascending hot-spring waters, if metalliferous, may deposit different ores with an orderly vertical distribution. Existing veins now mined often show this arrangement of metallic sulphide.

2. Ascending hot *alkaline* waters coming up through crushed and reopened veins containing pyrite (or marcasite) react with this sulphide, and zinc, lead, copper or silver, if present, is thrown down as sulphide.

3. Ascending hot *acid* waters may leach the lower levels of reopened veins and deposit gold, silver and copper upon cooling at higher levels.

* The full results of this very important experimental work of Dr. Stokes will soon be published. See, also, by him, "Pyrite and Marcasite," *Bull.* 186, *U. S. Geol. Surv.*

Silver-Mining and Smelting in Mongolia.

BY YANG TSANG WOO, TONG SHAN, CHINA.

(New York and Philadelphia Meeting, February and May, 1902.)

I WILL endeavor to describe the methods of silver-mining and smelting employed by the natives in Mongolia. Modern methods have been applied there, but with little success; and, since they are familiar to most members of the Institute, I will simply mention that the failure was due to the high price of coke used in smelting the ore in modern furnaces, and to the unsuitable mill-machinery employed for concentrating the galena, which is finely distributed in the ore.

The Jehol silver-mines are situated about 45 miles NE. of Jehol, the capital of Mongolia. They embrace two mines, 5 miles apart,—the Ku Shan Tze mine and the Yen Tung Shan mine. They were first worked by natives 50 years ago, about the time when mining was so flourishing in other parts of the world,—for instance, in California and Australia. The upper part of the vein is galena mixed with iron-stone, and is 2 to 4 ft. thick. At lower levels the vein is composed of silver-lead ore running between quartz-porphyry walls. Limestone, talc and black shale, colored by graphite, are found in other parts of the mine. Crystalline limestone is found 1 mile NE. of Ku Shan Tze. Granite is encountered in the Yen Tung Shan mine.

Mining.—The native method of working the mines is most primitive. The same method may have been employed a thousand years ago. A small inclined shaft, 4 ft. by 4 ft., is sunk in the vein-stuff where the appearances are most favorable. Another shaft is sunk 20 or 30 yds. away, for ventilation. The shaft follows the vein in a zigzag fashion in whatever direction the vein appears to be richest. Timber is used only in soft ground. Where the ground is hard, the roof is cut into an arch-form. In some places, instead of using ladders, steps are cut in the rock, just wide enough to hold one foot. The deepest native workings are 400 ft. below the

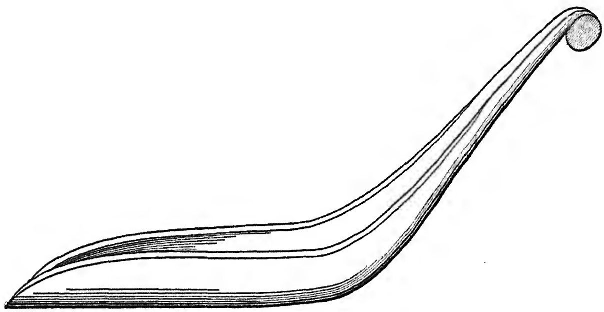
surface. As the workings are above water-level, very little water is met with. The water in the bottom of the workings is carried up to the surface in willow buckets by boys. When the water is abundant and requires several men each shift to drain the mine, sumps 3 ft. by 2 ft. are made every 4 or 5 ft. along the inclined shaft. Men are placed at every sump to bail up the water to the next higher sump, and so on to the surface. Although labor is cheap in China, this method of draining a mine is very expensive. When 50 or more men are employed in bailing water from one mine, it would be much more economical to use steam-pumps. Formerly black powder was used for blasting. Dynamite was introduced by European engineers in 1889. Since then, the miners will not employ any ordinary explosives, but only dynamite, in hard rocks. Where the ore is rich, the drill and hammer are generally used for picking out the ore. Blasting is resorted to where the ore is poor. Boys carry the ore up to the shaft-mouth in round, shallow willow baskets.

The miners do not receive any regular wages. The owners of the mine supply them with board and lodging, and they receive a part of the proceeds of the smelting. If the ore is worth 150 to 200 ounces a ton, each miner may get $20 to $30 a month. In case the ore is poor, containing less than 80 ounces a ton, it would only pay for the fuel used in smelting, and for the men's board and the explosives. At one time, when a company was formed to work the mines, the company collected 30 to 40 per cent. of the proceeds of the smelting, according to the richness of the various workings; and the contractors received the balance as payment for the expenses of mining the ore and smelting it, including the explosives, tools, fuel, and the miners' wages. The company had only to look after the general drainage of the mine and the timbering of the main levels. The highest output of silver was in 1894, amounting to 140,000 ounces. The yearly average is between 80,000 and 100,000 ounces.

Smelting.—The ore as it comes out of the mine is first dressed by breaking it into small pieces about 1½ in. square and picking out the waste rock. The waste ore is then concentrated by washing in a spoon-like pan, as shown in Fig. 1. The water used for washing is mine-water pumped from the shaft. It is

allowed to run into ditches about 4 ft. wide, 3 ft. deep, divided into compartments 5 ft. long, and lined with timber so that the sides will not cave in. The pan floats in the water, is held by both hands, and a wavy motion is given to it. The heaviest particles settle at the back or bottom of the pan. The dressed

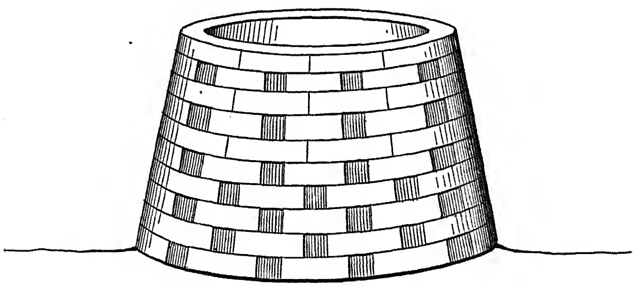
FIG. 1.



Concentrating-Pan.

and concentrated ore is then roasted in a primitive roasting-furnace. It is simply a round wall of blue bricks, perforated at intervals to allow the escape of gases, as shown in Fig. 2. A space 3 ft. wide is left open for a door. When the furnace is charged full, the door is built up. The bottom of the fur-

FIG. 2.

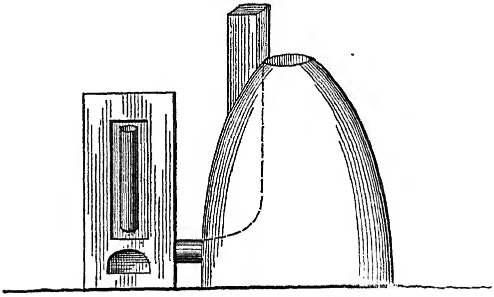


Mongolian Roasting-Furnace.

nace is composed of wood-ashes, 1 ft. deep. The furnace is 5 ft. high and 6 ft. in diameter. A layer of charcoal is first laid in the bottom of the furnace, then a layer of ore, then a layer of charcoal and another of ore, and so on, till the furnace is full. It requires a week's roasting before the ore is sweet.

When cold, the roasted ore is transferred to a small smelting-furnace, as shown in Fig. 3. It is built of sun-dried bricks, is 3 ft. high and 1 ft. in internal diameter, cone-shaped, and open at the top, so that the ore and flux can be fed in. Inside of the furnace there is a protrusion, so that the blast may be directed toward the ore. The bellows consists of a square

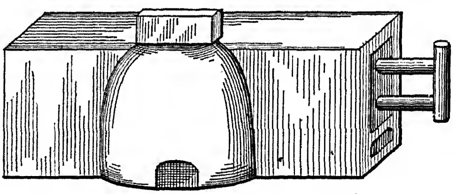
Fig. 3.



Smelting-Furnace used in Mongolia.

box of wood, 4 ft. by 3 ft. by $1\frac{1}{4}$ ft., with a valve at each end, as seen in Fig. 4. It is worked by two men pulling a rope on each side of the bellows. The furnace is dried by heating with charcoal the night before using. The bottom is lined with wood-ashes. A layer of charcoal is first put in, and then a layer ot ore mixed with a proper proportion of flux, which is composed of old cupel-bottoms containing about 80 per cent.

Fig. 4.



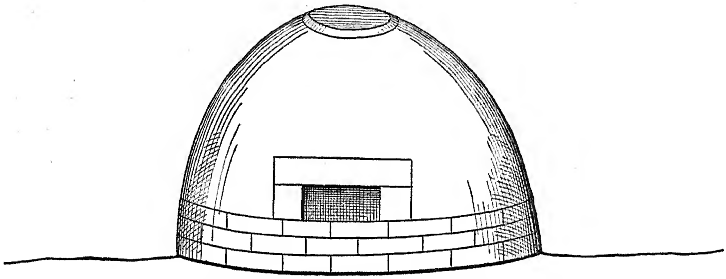
Bellows.

of lead oxide. The blast is put on. Ore and flux are added from time to time, till there are about 100 lbs. of silver-lead in the bottom. The slag is taken out through a hole near the bottom of the furnace. When there is sufficient lead in the bottom, water is poured into the furnace to quench the fire and cool the silver-lead. A big hole is made at the bottom of

the furnace, and the lead is extracted in the form of a round cake.

It is cleaned and transferred to a crude cupel-furnace, as shown in Figs. 5 and 6. The cupel-furnace is about 4 ft. long, 3 ft. wide and $2\frac{1}{2}$ ft. high, and built of rough mud bricks.

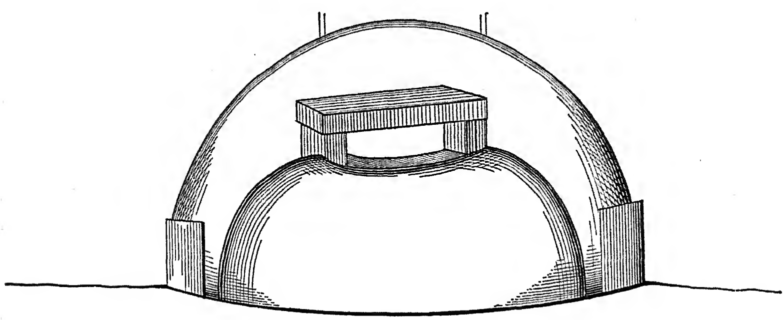
Fig. 5.



Mongolian Cupel-Furnace, Front Elevation.

These furnaces are located in groups of a dozen or more, as occasion may require. In appearance they resemble the *adobe* ovens used in Mexico. The cupel proper, or muffle, is 18 in. by 12 in. by 8 in. The cupel-bottom, Fig. 6, is composed of fine sifted wood-ashes collected from kitchen fires. A pile of

Fig. 6.



Cupel-Furnace, Showing Cupel in Interior.

ashes is dumped on the ground, and made into an oblong shape. It is hardened by pressing on it with one foot. The silver-lead is wrapped in coarse paper and placed on top of the ashes. Then a muffle is made over it by forming an arch with mud bricks. Charcoal is piled on top of the muffle and ignited.

Mud mixed with straw is smeared over the charcoal, leaving a hole in the top for ventilation. The complete cupellation of 100 lbs. of lead takes about 10 hours. When the silver brightens, water is poured on, and the silver is extracted with tongs, washed, and cleaned with brushes. It is then cut up, and is ready to be made into sycee-shoes, which weigh from 5 to 50 oz. each. The fineness of the silver is 995.

It is a curious fact that almost every one in the neighborhood of the silver-mines has some crude method of extracting silver from galena. All the stolen ores are smelted by the wives and children of miners. The smoke from their blast-furnaces often gives a clue to the men sent out to arrest the people who smelt ores in secret.

The Development of the Modern By-Product Coke-Oven.

BY CHRISTOPHER G. ATWATER, NEW YORK CITY.

(New Haven Meeting, October, 1902.)

THE object of this paper is to describe and discuss the progress that has been made, up to the present date, in the development of the modern by-product coke-oven. There are few members of the Institute who have not heard more or less of the by-product oven-installation, and there are many whose acquaintance with it is intimate and practical. Since the general opinion on the subject has hardly become crystallized as yet, it is hoped that this paper will at least furnish matter for discussion.

In order to obtain an idea of the present status of the industry in the principal iron-producing countries, the following table has been prepared:

TABLE SHOWING PROPORTION OF COKE MADE IN BY-PRODUCT OVENS IN VARIOUS COUNTRIES.

United Kingdom (1898, *Mr. George Beilby*).

	Short Tons.	Per Cent.
Coal coked in by-product ovens, ...	1,400,000	7.9
Coal coked in blast-furnaces with by-product recovery, ...	2,240,000	12.7
Coal coked in non-by-product ovens, . .	14,000,000	79.4

United States (1901, *Calculated from "Mineral Resources"*).

	Short Tons.	Per Cent.
Coal coked in by-product ovens, . . .	1,573,200	4.6
Coal coked in non-by-product ovens, . .	32,634,765	95.4
Total coal coked, ...	34,207,965	
Coke made in by-product ovens, . . .	1,179,900	5.4
Coke made in non-by-product ovens, . .	20,615,983	94.6
Total coke made, ...	21,795,883	

Germany (1900, "*Westfälisches Kokssyndikat*").

	Short Tons.	Per Cent.
Coke made in by-product ovens (estimated), .	6,700,000	40
Coke made in non-by-product ovens (estimated),	10,047,300	60
	16,747,300	

The table shows that of the coal coked in 1898, in the United Kingdom, practically 8 per cent. was in by-product ovens; 12 per cent. was used directly in the blast-furnace and the by-products recovered from the blast-furnace gas, and 80 per cent. was coked with the loss of the by-products. These figures are from the estimate of Mr. George Beilby. The figures for the United States show that a little less than 5 per cent. of the coal was coked in by-product ovens in 1901, while 95 per cent. was coked without the recovery of by-products. A little over 5 per cent. of the coke made is from by-product coke-ovens, the discrepancy being due to the increased yield of the by-product oven over the beehive process. In Germany, in 1901, the total coke production was nearly 17,000,000 net tons, as given by the Westphalian Coke Syndicate, but no figures are given as to the proportion made in by-product ovens. The beehive oven, as we understand it, practically does not exist in Germany, all the ovens being of the retort shape, either with or without the recovery of by-products. The only way to arrive at an approximate figure for the division is by taking into consideration the fact that of the 13,000 ovens built by Dr. C. Otto and Company, almost 40 per cent. are by-product ovens. Not allowing for the slightly greater yield of these, it may, therefore, fairly be estimated that 40 per cent. of the output is by-product coke. Though this figure is open to question, it shows in any event the strong contrast between the condi-

tions in Germany and those in England and America, and fairly indicates the probable line of future development.

The progress we have made thus far is indicated in Fig. 1. This is constructed from data relating to the ovens in operation and under construction, taking them as nearly as possible in the order of their undertaking, and showing the conditions up to the present time. It may be mentioned here that, when the ovens now in course of construction are com-

FIG. 1.

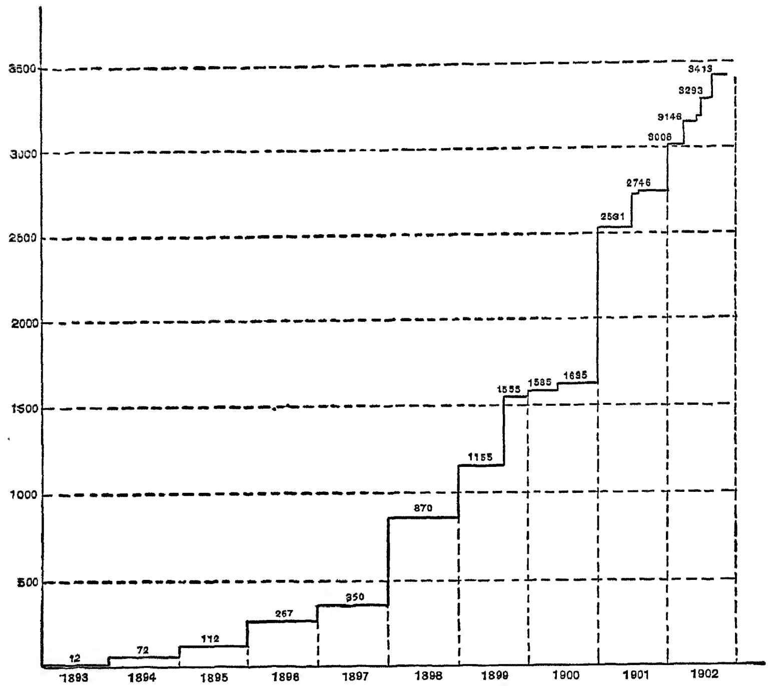


Diagram showing By-product Ovens Under Construction and in Operation, in the United States and Canada, for Each Year since 1893.

pleted, they will add, approximately, 3,000,000 tons of coke per year to the present output, as shown in the preceding tables, so that the proportion of by-product coke will rise to nearly 13 per cent., provided there is no other increase in the total production.

We will now turn to the development of the oven itself. In speaking on this point, I shall confine myself to the consideration of the type of oven in the construction of which I am

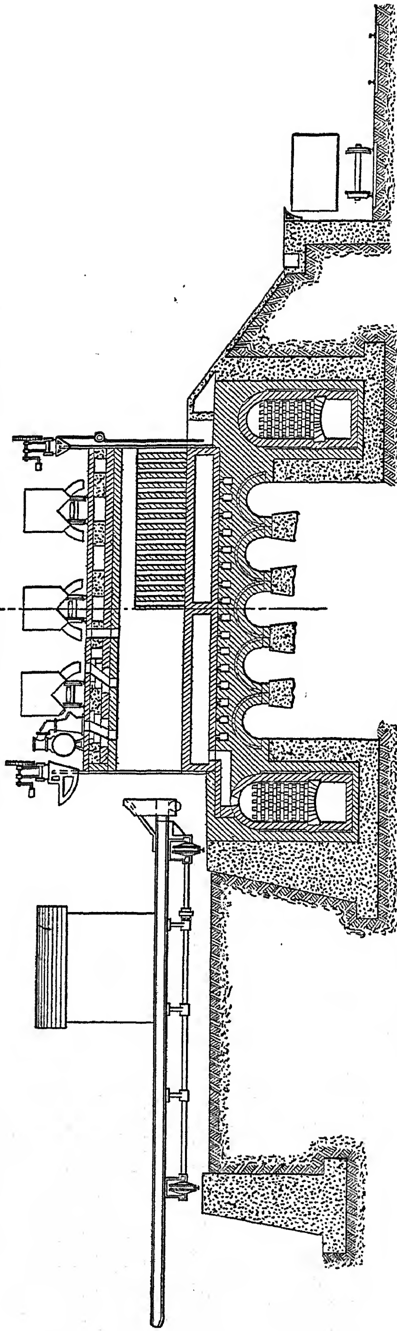
engaged and concerning which I can speak with authority, viz., the Otto-Hoffmann or vertical-flue ovens. In as brief a manner as possible, I shall endeavor to trace the development of this type of by-product coke-oven from its introduction in this country up to the present time. In the early stages of the industry the ovens adopted were direct copies of those which had proved successful abroad. This was, of course, the natural thing to do in the transplanting of so expensive a process. As the industry developed it began to receive individuality from its new environment, and developed on lines somewhat different from those followed in the place of its origin. As it has been with the blast-furnace, the rolling-mill, the Bessemer converter, and the open-hearth furnace, so it has been with the by-product coke-oven.

In Fig. 2 is shown a cross-section of the Otto-Hoffmann oven essentially as built in 1894, for the Cambria Steel Company, at Johnstown, Pa., at the first plant making blast-furnace coke in this country. This type, with various improvements in detail, was also built for the Glassport, Everett, Sydney, Hamilton, Camden and Lebanon plants. As shown in the figure, it consists essentially of a retort built of refractory materials, 33 feet long, 18 to 20 inches wide and 6 feet high. The ovens are separated by a division-wall containing vertical flues, through which the heat is supplied. The foundations consist of masonry arches running lengthwise of the battery, the two outer arches forming the regenerative chambers, which are the characteristic of this system of firing. Through these regenerators the outgoing hot gases and the incoming air for combustion pass alternately. The regenerators are provided with reversing-valves at the ends of the oven-battery, in connection with the necessary chimney-stacks. The gas is admitted alternately by two burners, one at each end of the oven, to the space beneath the division-wall flues. The air for combustion rises from the regenerator below to the space beneath the oven-floor, and passes to the combustion-chamber beneath the flues. The passage of the hot gases is up the vertical flues in one-half of the division-wall, along the horizontal flue at the top and down the flues at the other half of the division-wall to the regenerator below. The characteristics of this construction are:

1. The vertical flues;

Fig. 2.

Section Through Retorts. | Section Through Side Wall.



Otto-Hoffmann Ovens, Showing Charging Larries, Pusher and Quenching Platform.

2. The use of regeneration.

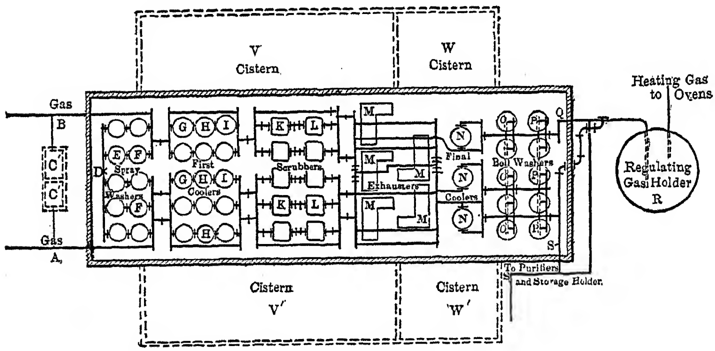
In the original plants the coal was supplied by larries pushed by hand to and fro from coal-hoppers, sometimes at a distance. The doors were raised by a hand-winch; the coke was pushed out on a floor and loaded by hand into cars; the pusher carried its own engine and boiler, and, in general, the use of labor-saving machinery was conspicuous by its absence. This is the method employed by the plant at the "Koenig Ludwig" mines, in Germany, which, though of more recent construction, still shows these features. These methods were modified in the Everett plant, where the single electrically-operated larry fills all the charging-holes at once. This larry is supported on bridges above the ovens. An electric door-hoist and pusher, and an inclined coke-car, which receives the coke as it is pushed out and allows it to be quenched with a minimum of hand-labor, have been introduced.

The principal innovation in this plant, however, was the introduction, on a large scale, of the principle of division of gases, by which the first portion of the gas evolved from the ovens was separated from the latter portion and illuminating-gas of high candle-power obtained. This was accomplished by means of a complete duplicate condensing-system for the two gases from the collecting-mains onward, and has come to be recognized as a method of great importance in its bearing on the gas-industry. The development of this principle is due to Dr. F. Schniewind, of the United Coke and Gas Company. The method is shown in detail in Fig. 3, which is a plan of the Everett condensing-plant. The hot gas from the ovens comes in through the separate pipes, A and B, the former carrying the rich and the latter the poor gas. It passes through the cooling- and scrubbing-apparatus at E, F, G, H, I, K and L. The two systems are entirely distinct, except for the by-pass valves at D before the coolers and those at the exhausters M, the latter making it possible to interchange the exhausters. From these the gas passes to the final coolers, N, and the ammonia-washers, O and P. The rich gas passes to the purifying-house and the poor gas to the small storage-holder and thence to the oven fuel-mains. There is a by-pass between the two systems here to enable the fuel-gas supply to be always equal to the demand. The results of this plant show that from 6,000,000 to 7,000,000

cu. ft. of 18 candle-power gas from the coke-oven plant can be turned into the city mains daily without enrichment.

The plant at Sydney was of similar character, except that circumstances did not justify the division of the gas or the use of all labor-saving devices. Since this plant has come into operation the process of coal-compression has come into prominence and has been introduced there. The Dominion coal used at the plant is high in volatile matter and yields a coke of a somewhat brittle nature, which is not the best adapted for blast-furnace use. By compressing the charge of coal into a solid cake, which is pushed endwise into the oven, in place of charging the coal loose, a great improvement has been made in

FIG. 3.



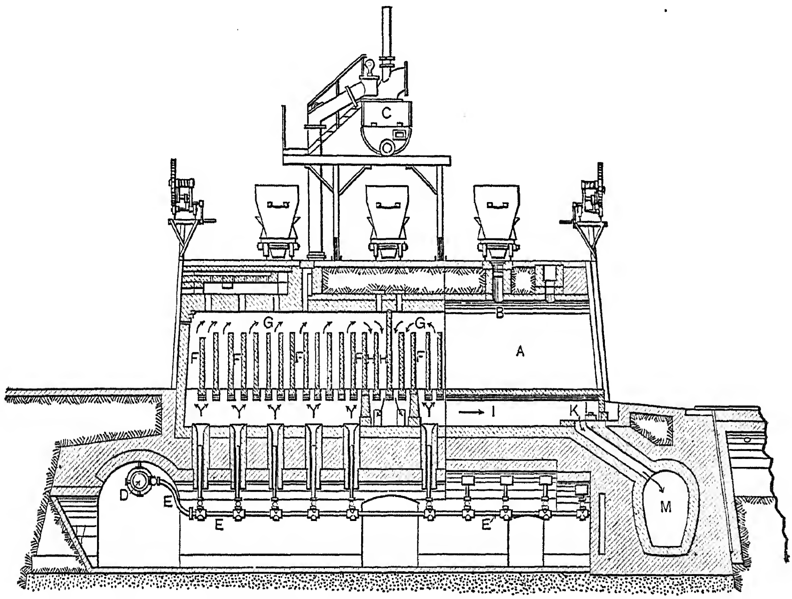
General Plan of the Everett Condensing-Plant.

the coke-structure. The apparatus for doing this consists of a form or mould of rectangular shape with movable sides, ends and bottom. The coal is stamped into it with rammers, and the cake pushed, together with the bottom, into the ovens, and the bottom is then withdrawn. The machinery for this was made abroad, as the process has not been put into active operation elsewhere on this continent. It has been in use in some German and English plants for several years and with good results. The principal advantage of the process lies in its effect on the coke-structure. A certain gain is also made by the increase in the capacity of the oven, but this is partly neutralized by the high cost of the compression apparatus. It may be stated as follows:

Increase in oven-capacity per cu. ft., ...	45 per cent.
Less clearance, ...	15 " "
Net increase in amount charged, ...	30 per cent.
Increase in coking time, ...	20 " "
Net increase in coke-yield, ...	10 per cent.

This gain is to be balanced by the installation- and maintenance-cost of the compressing-plant, and the extra condensing- and ammonia-apparatus required for the handling of the increased amount of gas-liquor, due to the 8 or 10 per cent. of

FIG. 4.



Otto-Hilgenstock By-Product Coke-Oven.

water required for the compression. If a washed coal is used the water is already present, so the increased coking time will be but 10 per cent. and the increase in output 20 per cent. The process, of course, has its greatest value in handling coals that cannot be successfully coked in any other way. It is impracticable to employ it in the case of swelling and easily fluxing coal.

At the plant at Hamilton, Ohio, the gas is divided, though the plant shows otherwise no radically different features from the Everett installation.

Figure 6 is an ideal view in section of the 100-oven plant at Camden, N. J. It shows in a detailed manner the labor-saving appliances already mentioned in connection with the Otto-Hoffmann oven of practically the original type. Here are seen the duplicate-mains, the coal-larry, and the over-head supporting bridges. The machinery is operated by electricity throughout. The coke, however, is handled on a quenching wharf in the old way.

About the time the Hamilton plant was built, the development of a type of oven in Germany, the invention of Mr. G. Hilgenstock, of Dr. C. Otto and Company, and known as the underfired oven, began to come into prominence abroad. A section of this oven is shown in Fig. 4. The simplicity of its design is attained, partly, by the omission of regenerators, and in part by the introduction of the gas-firing at different points underneath the vertical flues rather than at the end of the oven alone. The gas-inlet forms, practically, a Bunsen burner, and the combustion is complete with approximately the theoretical amount of air. Its advantages of simplicity and a better distribution of the gas in the flues, and consequently more even heating, were sufficient to recommend this oven in comparison to the Otto-Hoffmann oven, especially where the coals carbonized did not give enough gas to make the surplus a question worth considering, and where the outgoing heat could be made readily available by the use of waste-heat boilers. The embodiment of its greatest point of advantage, *i.e.*, an improved heat-distribution in an oven without omission of the regenerators, which are essential to the delivery of the maximum amount of surplus gas, gave rise to what is known as the Schniewind or United-Otto type of oven. A longitudinal and a transverse section of this oven are shown in Figs. 5 and 7. The essential points of difference between this oven and the Otto-Hoffmann and Otto-Hilgenstock may be summed up as follows:

1. The introduction of the underfiring principle in connection with the use of regenerators.

2. The use of a columnar substructure instead of brick arches, admitting anchorage-rods beneath the ovens and facilitating complete inspection while in operation.

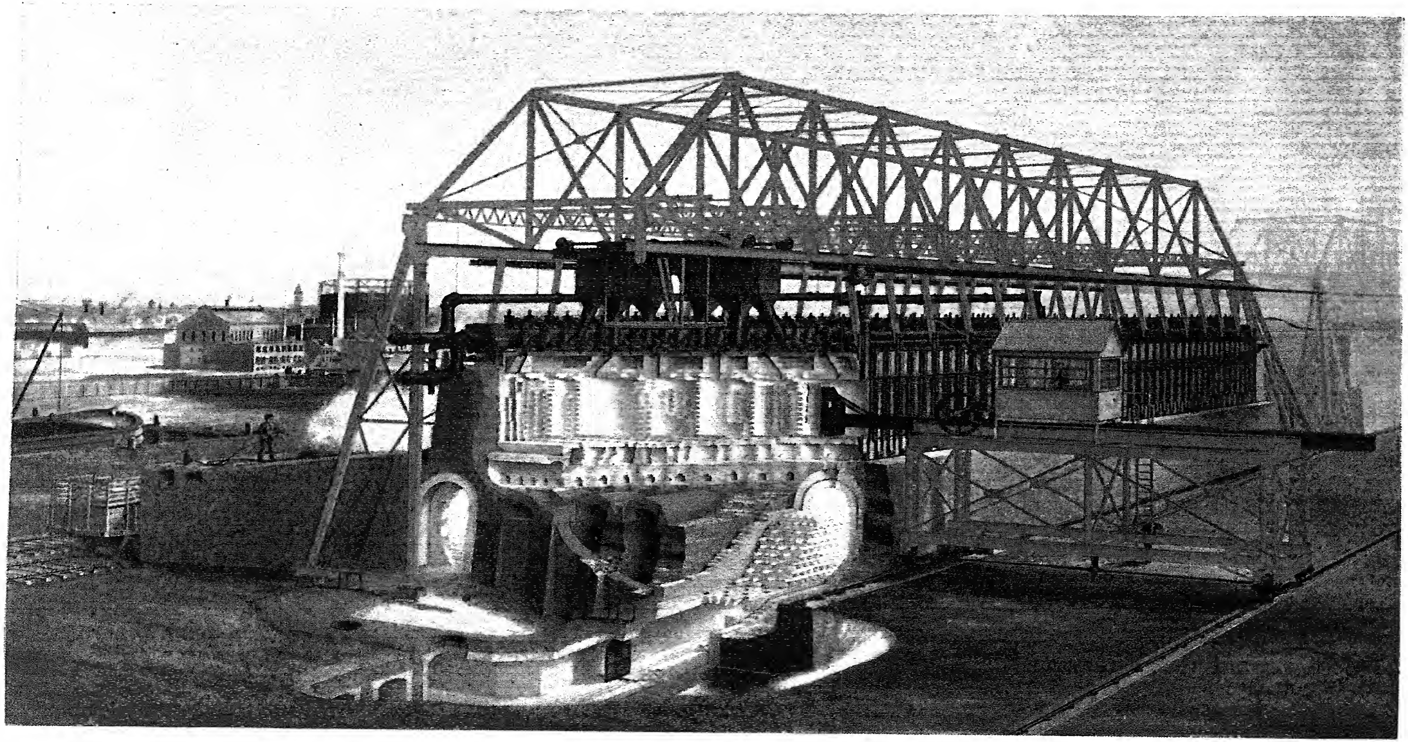


FIG. 6. SECTIONAL VIEW OF CAMDEN FURNACE

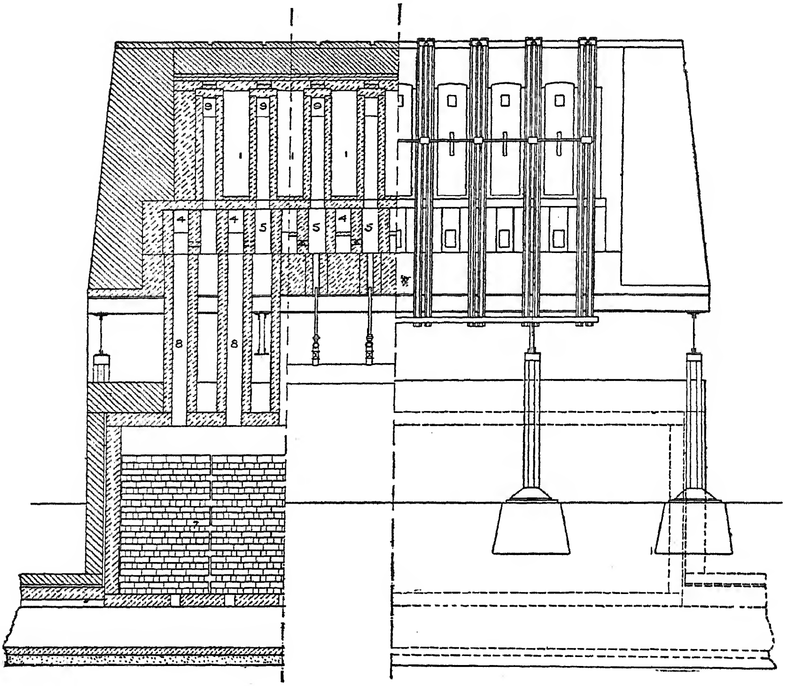
3. The entire separation of the regenerative chambers from the oven-supporting frame-work.

An oven built in accordance with these principles affords easy access to every part; the foundation is not disturbed by the regenerative chambers, and it becomes possible to extend the length from 33 to 43 feet, which would have been entirely out of the question on the end-fired Otto-Hoffmann oven. With coals of a shrinking nature this presents no difficulties, and admits of an 8-ton charge in place of 6 tons, with corresponding decrease in the operating costs per ton of output.

Figure 8 shows a cross-section of a modern plant. The coal comes in on the railroad track on the right hand, and is raised to the coal-bin by the conveyor. It is discharged from the bin through the spouts into the larry which moves along on top of the ovens, and from which the coal passes through eight openings to the oven. After coking, it is pushed out by the ram 21 moving on the carriage 22, the coke being received in the inclined quenching-car 20, and, after cooling, dumped into the coke-car 23. The gas passes through the two uptakes 27 and the gas-valves 28 to either of the two mains 25, one being for the rich gas and the other for the poor. The general arrangement throughout aims to receive coal and deliver coke with a minimum of handling. Furthermore, it is adapted to the usual character of ground-conditions; does not require excavation to any great depth, or any filling-in; and thus avoids the heavy retaining-walls usually seen in the older plants. The substructure of the ovens is concrete or steel. In the plant now under construction at Sharon, Pa., the liability of the Shenango river to sudden floods made horizontal regenerators of the usual type impracticable, so the regenerators were built in vertical form, similar to the usual hot-blast stove.

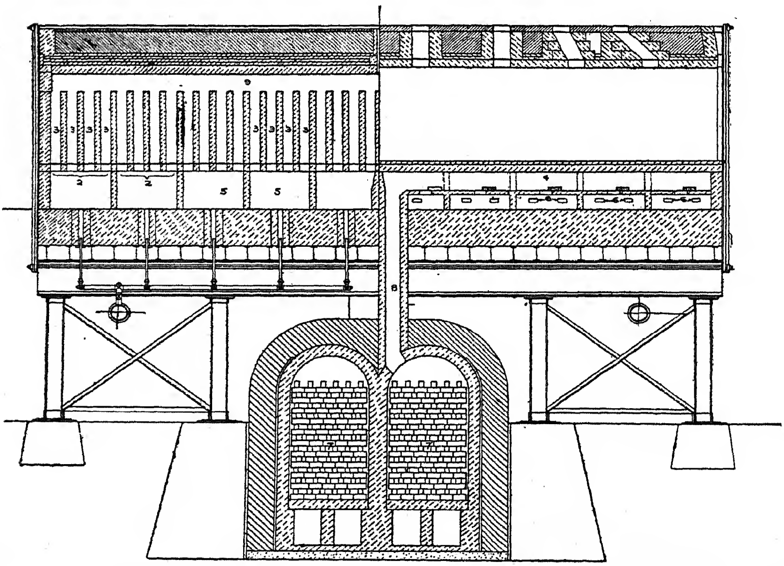
Another innovation in the latest plants is the use of a new form of quenching-car, the invention of Mr. Edwin A. Moore. It is designed to cool the coke thoroughly with a minimum amount of water and to preserve its silvery luster, and at the same time to allow the coke to be loaded directly in railroad-cars. It is shown in detail in Fig. 9. It consists of a moving, covered car, which receives the charge just as it is pushed out, without breaking it down at all, and quenches it by water supplied to nozzles inside. The top and sides of the car are of

Fig. 5.



Longitudinal-section of United-Otto Ovens (Schniewind Type).

Fig. 7.

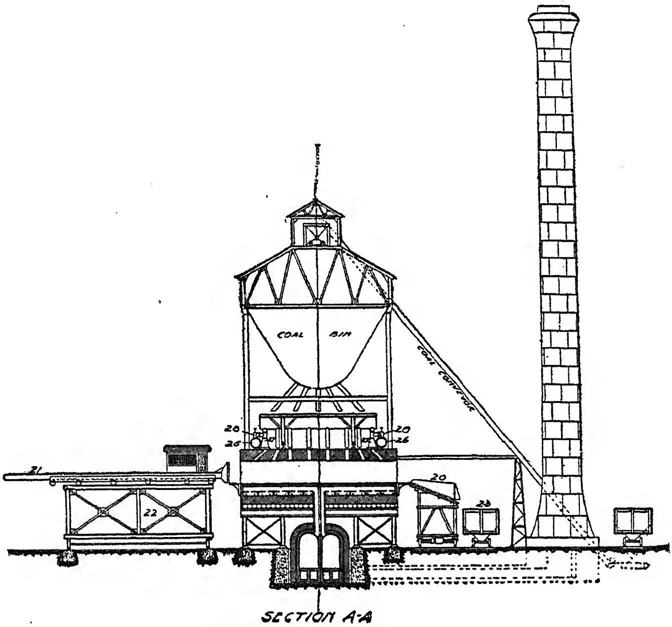


Cross-section of United-Otto Ovens (Schniewind Type).

cast-iron plates, so that the steam is confined and assists in the quenching. The bottom of the car is movable, and aids in receiving the charge unbroken and removing it when quenched. The results obtained in an experimental car of this design have proved sufficiently satisfactory to justify the cost of its introduction.

The development of the by-product oven has of necessity been strongly influenced by the materials available for its construction and the methods employed in putting them together.

Fig. 8.



Section showing Plant of the United-Otto Ovens (Schniewind Type).

The working-out on a commercial scale of so specialized a process might easily be supposed to have called for a number of special devices. Such has been the case. The resources of this country in the production of refractory materials have been well tested, and it has proved entirely possible to obtain suitable fire-clay shapes at a satisfactory price. The manufacture of silica-brick and the so-called quartzite-clay shapes have made rapid strides in the last few years; and by adhering to shapes of small dimensions, in which the use of machinery is

able to counteract the cheaper hand-labor obtainable abroad, we have been rendered practically independent of the foreign block-maker. The difficulty in building a wall of small blocks, with the minimum thickness of joints, without a great deal of expensive labor in cutting the blocks to lay level courses, has been overcome by the use of special grinding machinery, by which the blocks are all exactly sized before they reach the mason's hands. Large carborundum wheels are used, driven at high speed; and by the use of fixed guides and a system of gauges the work is done by low-grade labor with better results than the best hand-labor and at a price very much lower. The introduction of this method of doing the brickwork has resulted in the production of masonry that could practically be obtained in no other way, as well as the saving of thousands of dollars.

The use of steel supports has made it necessary to insulate the structural work from the heat with a minimum amount of masonry. For this purpose the hollow tile, so extensively used in modern building construction, has been found most admirable, and has also been employed in covering the top of the ovens.

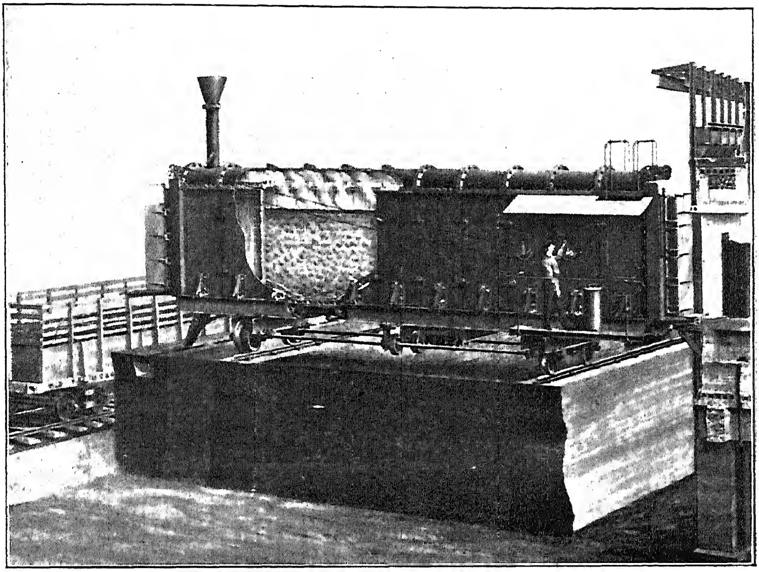
The development of the foreign plants shows certain variations from the development here. The use of the surplus gas has received very little attention there, this being partly due to the quality of their coal. As they have cheap labor they have not been as ready to introduce automatic machinery, which we have found necessary.

Figure 10 shows the "Kaiser Friedrich" plant at Baron, Germany, in which the gas-collecting mains are raised high above the top of the ovens, the object being to avoid the heat radiated from the top and diminish the pitch formed in the mains. This device has met with sufficient success to justify its adoption in other plants—for example, the "Lothringen" works.

An interesting series of tests was made at Sydney (at Dr. F. Schniewind's request), concerning the progress of coking in the oven. Holes were bored in the oven-door at various points, as shown in Fig. 12, and temperatures were taken at intervals during the coking period. These temperatures were plotted in curves, as shown. These curves group themselves into two

classes. Those very near the heating-walls rise rapidly; those in the middle of the oven-charge remain at a lower temperature (about at the point of vaporization of water), until some time has elapsed, then rise rapidly as the coking becomes complete. This shows conclusively that the gasification begins at the oven-walls, and that it proceeds gradually from the oven-wall towards the middle of the charge, and that the evolved gas passes upwards along the oven-wall and through the fissures

FIG. 9.

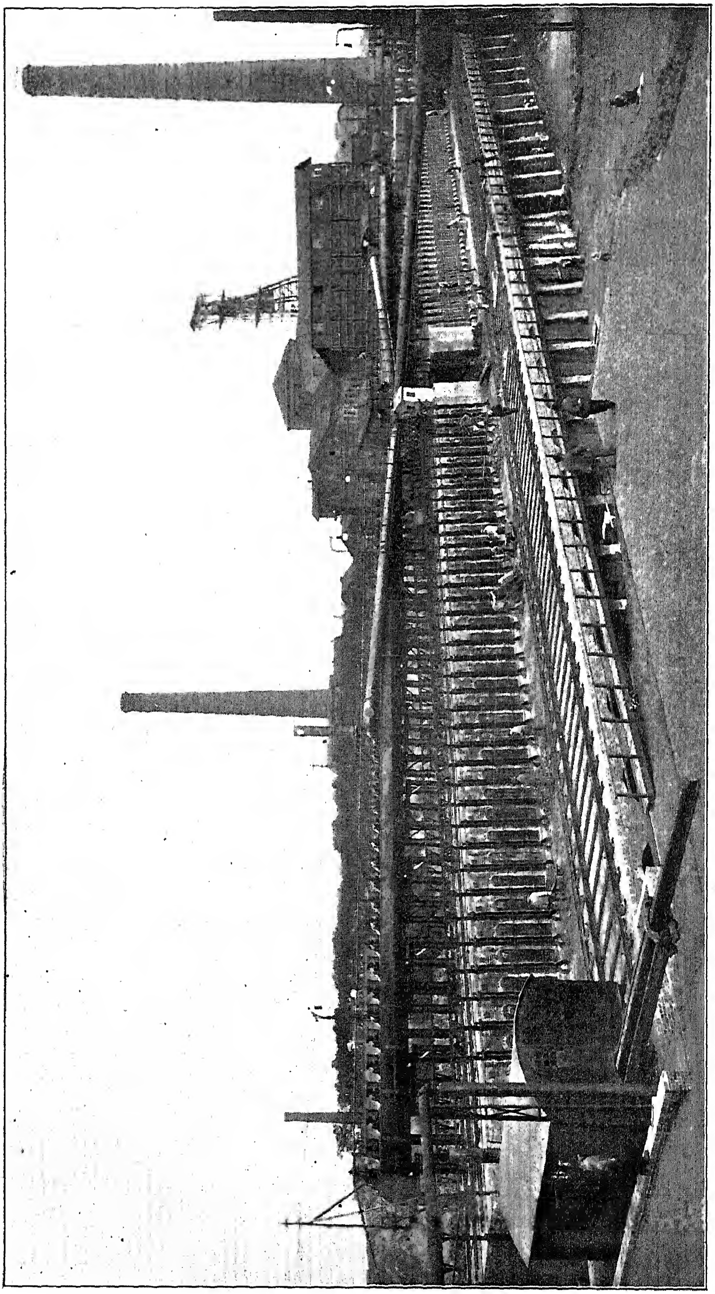


Moore Coke-quenching Machine.

in the coked portion. During its passage it has opportunity to deposit a certain portion of its carbon in graphitic form, which accounts in part for the increased yield of the by-product oven over the beehive. Tests similar to these were made by Dr. C. Otto and Company, the results of which were given out in a recent paper by Mr. Gustav Hilgenstock. Though the readings were taken independently, and in a somewhat different position in the oven-charge, the curves are almost identical with the ones shown in Fig. 12.

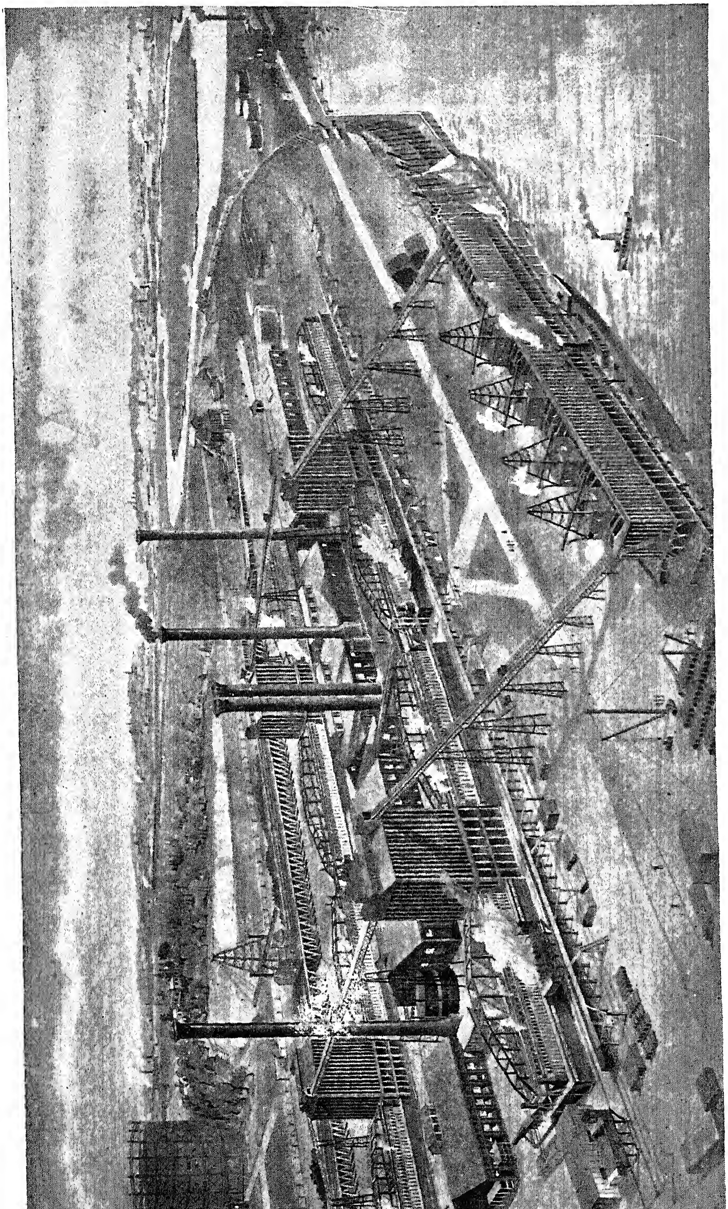
The progress that the preceding pages are intended to chronicle will fairly justify some satisfaction in the retrospect, but a

Fig. 10.



Coke-oven Plant, "Kaiser Friedrich," Baron, Germany. 80 ovens.

Fig. 11.



Works of the New England Gas and Coke Co., Everett, Mass.

survey of the field still to be covered, in the light of a keen appreciation of the ultimate possibilities, does not increase this feeling. Much has been done, but more remains to do. Enough, however, has been accomplished to show that the progress of the modern retort-oven towards its true position, not alone in the iron and chemical industries, but as an essen-

Fig. 12.

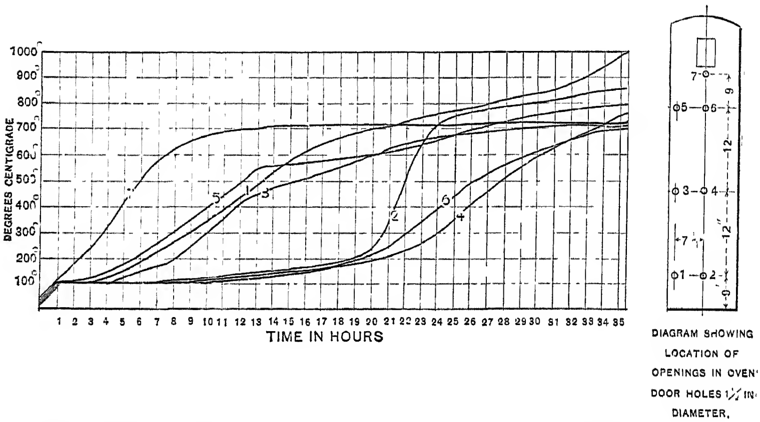


Diagram Showing the Temperature in the Oven-charge at Different Points. Sydney Plant, October, 1901.

tial factor in the production of the gaseous and solid fuel used throughout the country, can be considered as only a matter of time.

In conclusion, I wish to acknowledge my indebtedness to Dr. F. Schniewind for the invaluable aid he has afforded me in the loan of photographs and data. Without his kindly co-operation this paper could hardly have been written.

The Valuation of Mines of Definite Average Income.

BY H. D. HOSKOLD, INSPECTOR-GENERAL OF MINES OF THE ARGENTINE REPUBLIC, AND CHIEF OF THE NATIONAL GOVERNMENT OFFICES OF MINES AND GEOLOGY, BUENOS AIRES, S. A.

(New Haven Meeting, October, 1902.)

As the theory and the practice of valuing mines have never been discussed in the *Transactions*, a paper on the subject may be acceptable, even though not exhaustive. The method here indicated is set forth, not as a model of perfection to be followed absolutely, to the exclusion of any other system based on sound scientific, commercial and equitable principles, but merely as an aid to mining engineers and financiers in estimating the value of mining-property.

This paper is intended merely to point out certain financial features of the question, and not at all to go into the theories of the formation of mineral veins, extremely valuable as it must, of course, be to understand the laws of the earth's formation and of its various changes, which are the basis of such important sciences as geology and mineralogy, and highly useful as guides in determining the probable existence and extension of mineral deposits.

Financial Elements of Mine-Valuation.

The practice of basing the stock-exchange price of mining shares upon reports, periodically received from the mine-captain or manager, stating that in his opinion the mine is "improving" in this or that level, and is worth so much "per fathom," is, of course, absurd. Everybody experienced in metalliferous mining is aware that a mineral vein varies in thickness and also in percentage of metal in different parts of the same mine. According to the practice just indicated, a mine must have had as many values "per fathom" as there have been given reports upon it at intervals during the year,

and the shares bought and sold according to such representations must have varied similarly in price. Hence, if all the shares of the mine had been sold for cash according to any one of such stock-exchange valuations, the purchase-money may have been in excess or defect, according to the local variations in richness indicated by the periodical reports. It would be safer to assess the value of a mine upon the annual net yield, as determined in a proper financial manner.

When a mine is not fully developed, and its capacity of product and profit awaits future determination, the estimate of its present value is difficult. If attempted at all, it must be based upon the quantity and the quality of the mineral already opened up to view, and available for immediate extraction; and, in addition, upon the estimated future extension and yield under probable future conditions—a problem of "deferred benefit," the present value of which is to be treated in a different, special manner.

The estimate of probable future benefit from veins on which little or no work has been done is, of course, still more difficult and doubtful, because there is nothing to rest upon, except the general conclusions of science and practice, and also, perhaps, the analogies furnished by similar mines under exploitation in the same district. Frequently, however, such veins, called "mines," are to be inspected for vendors or intending purchasers. If any estimate of value can be given, it must be that of a probable future benefit, not only uncertain in itself, but also deferred for as many years as would be required to bring the mine to the anticipated productive capacity.

In the valuation of collieries there is greater certainty of a constant yield of mineral. For a fully-developed and producing concern, the present annual yield in tons of coal can be known, and the only difficulty in assessing the present cash-value of the mine consists in estimating the cost and market-price of a ton of coal for a future period of years. In the case of a proposed colliery, in land of which the valuable contents are, through geological investigations, local borings, actual mining operations in the vicinity, etc., more or less definitely known, all the conditions of development, markets, etc., still remain to be estimated. When this has been done as accurately

as possible, the present cash-value, as already explained, is to be calculated as the present worth of a probable future value.

When a mine has been laid out, and coal or other mineral has been extracted through a considerable period, it is often assumed, especially in the case of a colliery, that it will continue a given annual output for a certain number of years to come; and on this series of deferred benefits the present value is calculated. But circumstances may permit or require an augmented annual yield in the future; and this may shorten the duration of exploitation, and probable increase to that extent the series of annual benefits. Of course, future variations in cost of labor and supplies, or in market-price of product, may likewise affect, for better or worse, the estimate of present value. Some of these elements of cost may be foretold—such as the augmented cost of extraction due to greater depth attained in mining, or greater distance of underground transportation, as the levels are extended.

Evidently, in the face of such uncertainties, a precise determination of present value is not to be expected. Nevertheless, much can be done in the way of proper and prudent calculations; and estimates based on the scientific use of even partial data are much better than mere speculative guesses.

First, the quality of the available mineral, the cost of installation, the time required for preliminary development, the total period of productiveness and the annual profit have to be determined as correctly as the case permits. Next, the vendor and purchaser must agree upon the rate per cent. expected to be received by the latter for his capital or purchase-money; and also upon the rate per cent. for its eventual redemption. The present value of a unit of the yearly income (or the year's purchase) and the total value, including proper allowance for the redemption-fund, may then be determined by the technical expert in accordance with such agreement, or, in its absence, fixed by him as an arbiter.

In England, where the valuation of mines has long been practiced, it has been customary to allow the purchaser of mining-property a high annual interest. Upon collieries, for instance, the rate is from 14 to 20 per cent. per annum; and upon metalliferous mines still higher, because the risk is

greater. For foreign mines, the details of management, economy and profit are further removed from control, and consequently, as the risk is proportionally increased, the purchaser should reckon upon the allowance of a far higher rate, depending upon the class and character of the mine, and probably from 25 to 35 per cent. The lower the percentage allowed upon the capital to be invested, the higher the present value of "*unity*," or the year's purchase, and consequently of the total purchase-money,—and *vice versâ*.

The recouping, by the time the mine is exhausted, of the capital originally invested, is an element that should enter into every valuation; but in practical mining, unfortunately, it is too often neglected. Generally, the only thing done with relation to it is to "write off" the books of accounts a certain sum every year, but without depositing the sum in any bank as a redemption-fund proper. Such a fund should be made up by annual deposits or secure investments which will amount, on the exhaustion of the mine, to the original purchase-money. The need of such a fund will be more fully discussed further on.

Before 1877, valuations of mines were effected in England upon an erroneous basis. Such tables of values as were employed to aid financial transactions were calculated upon the blind assumption that the annual rate of interest for a redemption-fund would be the same as the rate expected or to be paid annually upon the capital invested, whatever that rate might be. In other words, it was assumed that the high rate of profit justly allowed to hazardous investment could be also obtained on deposits for the redemption of capital.

When the two rates did not differ much from 3 or 4 per cent., the calculation of present value was not seriously vitiated. But when the estimated beneficial or dividend rate rose to 20 or 25 per cent. for home mines and from 25 to 35 per cent. for foreign mines, the prudent rate to be reckoned for the redemption-fund could not possibly be so high. If it were so taken, the resulting estimate of the necessary annual contribution to this fund would be too small; and the calculations of the present value, thus involving too small an annual charge for redemption, would give too large a result in the present value. Many years ago, discovering this source of error, the

writer was led to frame new tables of valuation, which were published in 1877. These tables contemplated two different rates of interest: the variable or beneficial (dividend) rate, and the rate of redemption—the latter being assumed at such a low figure as could be obtained on deposits made for a period of years in permanent financial institutions.

Formulas for Determining Present and Deferred Money-Values.

Every beneficial interest or dividend of constant amount to be paid periodically, at the end of each year, may be considered as yearly income or annuity, either to terminate with the life of an individual or in a number of years given, or to be perpetual. Any such sum of money left unpaid for a number of years is called an annuity in arrears, and when not payable until after a fixed number of years it is said to be a deferred income or annuity. In either case the annuity is transferable, and may be purchased on certain agreed terms; but each class of annuity must receive a particular mode of treatment, according to the special circumstances.

If money could not be put to use and interest obtained for it, the value of an annuity would be equal to the amount for one year multiplied by the whole number of years the annuity had to run; but as simple or compound interest is involved in every case, it is clear that if A desires to sell to B any annuity which has to run a certain number of years, a definite interest or discount upon every yearly payment of the annuity must be allowed to B.*

To determine the total amount of an annual payment of $1 for n years, with compound interest, the following formulas may be employed.

Let $r =$ the interest (say, at 3 per cent.) on $1 for one year (or, say, $0.03); let $R =$ the amount of $1 with one year's interest, $= 1 + r$; whence, $R - 1 = r$; and let $n =$ any integral number of years.

At the end of the first year, the first payment of $1 would be due. At the end of the second year, this amount would

* *The Engineer's Valuing Assistant, or a Practical Treatise on the Valuation of Collieries and Other Mines.* H. D. Hoskold, London, 1877.

have increased to $R = 1 + r$; at the end of the third year to R^2; at the end of 4 years to R^3; and at the end of n years to

$$R^{n-1} = (1 + r)^{n-1}. \qquad (1)$$

For instance, if the term be 21 years, and $r = \$0.03$ (3 per cent.), the amount would be $R^{20} = (1.03)^{20} = \$1.806$, and so on, until for $n = 101$ the amount would be \$19.219.

The second annual payment of \$1 would, at the end of the period of n years, amount in the same way to as much as the first payment in $n - 1$ years; the third, to as much as the first in $n - 2$ years, and so on.

Let $M_n =$ the sum of all these amounts, *i.e.*, the grand total of all annual payments for n years with compound interest. Then,

$$M_n = 1 + R + R^2 + R^3 + \ldots\ldots + R^{n-1},$$

or the sum of a geometrical series of n terms beginning with unity and with the common ratio R. Multiplying both sides of this equation by R, and then subtracting it from the new equation thus formed, we have

$$M_n R - M_n = R^n - 1,$$

and, dividing both sides by $R - 1$, we have

$$M_n = \frac{R^n - 1}{R - 1};$$

or, since $R - 1 = r$,

$$M_n = \frac{R^n - 1}{r}. \qquad (2)$$

Thus, at the end of the first year and at 3 per cent., the amount would be $\frac{R^1 - 1}{r} = \frac{1.03 - 1}{.03} = \$1$. At the end of 20 years ($n = 20$), it would be $\frac{R^{20} - 1}{r} = \frac{1.806 - 1}{0.03} = \$26.87$; and for $n = 100$, $M_{100} = \$607.288$.

Let $V_n =$ the present value of \$1 due n years hence. In determining this, we simply reverse the above calculation for the amount of the first annual payment with compound interest. At the end of the nth year, that amount was found (1) to be

R^{n-1}, and at the end of the $n-1$st year, $\frac{R^{n-1}}{R}$. Since, by the terms of the problem, $R^{n-1} = \$1$, the value at the end of $n-1$ years would be $\frac{1}{R}$; at the end of $n-2$ years, $\frac{1}{R^2}$, and so on to the beginning of the term when it would be $\frac{1}{R^n}$. Hence,

$$V_n = \frac{1}{R^n}. \tag{3}$$

The present value at 3 per cent., compound interest, of \$1, payable after 20 years, would therefore be

$$V_{20} = \frac{1}{(1.03)^{20}} = \$0.554;$$

and, similarly, for a term of 100 years, the present value of \$1 would be \$0.052.

We may compute as follows the sum required to redeem the amount of \$1 in a given period; that is, the annuity or yearly sinking-fund which, at compound interest, will amount to \$1 at the end of n years.

Let S_n be the yearly payment for the sinking- or redemption-fund for a term of n years, to amount to \$1 at the end of that term. Formula (2), above, gives $M_n = \frac{R^n - 1}{r}$ as the amount of annual payment of \$1. To make this amount, whatever it be, \$1, the annual payments of \$1 with compound interest must be divided by $\frac{R^n - 1}{r}$; hence

$$S_n = \frac{r}{R^n - 1}. \tag{4}$$

If the rate be 3 per cent., and the amortisation is to be effected in 20 years, we have

$$S_{20} = \frac{0.03}{R^{20} - 1} = \$0.0372$$

as the annual payment required.

Similarly, for 30 years at 3 per cent., the annual payment would be \$0.02101 for each \$1 to be redeemed. At a rate of only 2.5 per cent., and a period of 30 years, it would have to

be \$0.0228—an illustration of the obvious and important proposition that the lower the rate of interest for redemption, the larger the annual payment required.

Let us now consider the question, how large an income or annuity (A) \$1 would buy at different regular rates (r') of annual profit (or beneficial interest, or dividends), allowing at the same time for the eventual redemption of the \$1.

We have evidently

$$A = S_n + r'. \tag{5}$$

That is to say, the beneficial rate or dividend, r', added to the necessary annual payment to the sinking-fund, will give the total income to be bought for \$1. For example, the annual payment to the sinking-fund, determined by formula (4) for a term of 20 years, at 3 per cent., would be \$0.0372 for each \$1 to be redeemed. Then, if the rate of annual net profit or dividend be 20 per cent., we have

$$A = \$0.0372 + \$0.20 = \$0.2372,$$

the total annual income to be purchased by the investment of \$1.

Clearly, also, for each dollar or unit of total income, or the annual dividend including the annual sinking-fund payment, the corresponding purchasing price, or year's purchase, or present value, P_n, would be the reciprocal of (*i.e.*, unity divided by) the sum of the yearly total income thus defined; for if in formula (5) the second term $S_n + r'$ be made equal to unity, then the first term must be made $\frac{A}{S_n + r'}$; and, for $A = \$1$, we have

$$P_n = \frac{1}{S_n + r'}. \tag{6}$$

This is a very simple and useful principle; but, if known, it had not found its way into English technical literature when the writer introduced it in 1877.

What has been said thus far is only a concise statement of the basis upon which the computation of any series of present and deferred values must proceed. Under the old method of

valuing mines in England, when the interest required upon the capital amounted to 20 per cent. per annum, it was assumed that the investment could, as previously noted, be eventually redeemed by sinking-fund payments at the same rate. The present cash value of unity, or a year's purchase, so calculated, was, of course, excessive, because the annual payment for the sinking-fund was made too small. It is unnecessary to illustrate this proposition by examples.

But the foregoing discussion contemplates an income, dividend or annuity which can be expected to begin immediately; whereas, the practical problem frequently involves a period of delay before the series of annual benefits begins, thereafter to continue for a certain number of years. In this case, if n be the number of terms in the series, the value of the series at the time of commencement will be, by formula (6),

$$P_n = \frac{1}{S_n + r'}.$$

To find the present value of P_n, recourse is had to formula (3),

$$V_n = \frac{1}{R^n},$$

which gives the present value of \$1 due at the end of n years. For this case, let t be the number of years before the beginning of the annuity, and the whole period to the end of the annuity be $t + n$ years. Hence

$$V_t = \frac{1}{R^t}$$

for the present value of \$1 due after t years, and for the present value of P_n dollars,

$$P_{t+n} = \frac{P_n}{R^t} = P_n V_t. \qquad (7)$$

Since the capital is subject, during the period of deferment, to the risks of mining, R in this formula should be taken as $1 + r'$.

Substituting in (7) the value of P_n from (6), namely, $\frac{1}{S_n + r'}$,

$$P_{t+n} = \frac{1}{S_n + r'} \cdot V_t, \tag{8}$$

which is the present value of a dividend of $1 per annum for n years, beginning after t years; interest being allowed on capital at one rate, r', and for redemption at another rate, r.

Suppose the period of payments, n, to be 20 years; the deferred period, t, 3 years; the rate of dividend, r', 20 per cent.; and the rate of interest for the sinking-fund, r, 3 per cent. Then

$$P_{t+n} = P_{3+20} = \frac{1}{S_{20} + 0.2} \cdot V_3, \tag{9}$$

in which $V_3 = \frac{1}{R^3} = \frac{1}{(1.20)^3} = \frac{1}{1.728} = 0.5787$; and the cash-value, P_n, or $\frac{1}{S_{20} + 0.20}$, at the beginning of the dividend period, as determined from formula (6), is 4.21557. Then, since $P_{t+n} = P_n V_t$, we have $4.21557 \times 0.5787 = 2.4395$; that is, $2.4395 is the present cash value of the yearly income of $1 for 20 years, beginning at the expiration of 3 years.

The old method of treating this problem was as follows:

The present value of 23 years of the estimated or regular annual dividends at 20 per cent., according to the old tables, was $4.92453, and the present value of the dividends omitted during the first 3 years was $2.10648. Subtracting the latter from the former, the present net value of the 20 deferred dividends was $2.81805, an excess over the true value, as above determined, of $0.37855. This difference would, of course, vary according to the length of the two periods and the rates of interest and benefit assumed.

Evidently, half-yearly or quarterly payments can with some variations be subjected to calculations under the same formulas, which apply to all certain payments at regular intervals.

It is hoped that the foregoing rules and principles, which have been condensed from an ample statement in the writer's book, already cited, and have been proved for many years and acknowledged to be sound in practice, as in theory, may be of service to those who are called upon to make calculations of this nature.

The Need of a Redemption-Fund.

The redemption of the investment is a question affecting particularly the holder of an entailed estate or an estate in trust; and, if he leases, it affects also the lessee. For the mine at length becomes exhausted; and, unless the holder has invested annually a certain portion of the royalty income, the heirs-at-law would be injured by the total loss of the mineral-title or fee, through such exhaustion. The owner or lessor, under such circumstances, has no right to enjoy and consume, in his own life-time, the whole income from the royalty on the mineral extracted from the estate. If suitable provision be made for redemption at the end of the lease, the annual installments will accumulate until the fund covers the original value of the royalty, and the lessor or his heirs will come again into possession of whatever amount was originally invested in the real estate, the value of which would be continued in another form, for the benefit of the legal successors.

The case of the lessee is somewhat different. In addition to his annual rent or royalty, he needs an annual profit. Yet, as the remainder of his unworked mineral is, year by year, further from the station of surface delivery, the expense of working continually augments. Moreover, the lapse of time may bring changes in commercial conditions, so that the income of the mine is more precarious. Still, when practicable, it is a good principle to count, from the start, upon a redemption of the capital. In assessing the probable annual income from a mine it is customary to estimate so much profit per ton as probably to be realized. But, even with constant markets, the working expenses year by year are greater, and it would consequently be well to consider the income as a yearly decreasing amount, and to take the average of a series of years as a sum to be reckoned in determining the total present or deferred value.

It is interesting to note that in a discussion of this subject provoked by the writer, one of the gentlemen* put the case in the following quaint manner:

"He thought that the foundation of the matter was simply this,—was it intended to eat one's cake, or have it? If one determined to eat one's cake, and

* Mr. Alexander Smith, North of England Institute of Mining Engineers.

that was understood definitely from the commencement, then there was no need of depreciation (redemption) fund; but supposing it was wanted to enjoy the cake and still have it, then it was necessary to provide for depreciation. He could hardly agree with Mr. Simpson, when he, speaking perhaps feelingly as a director of collieries, 'said that it was a difficult thing to set aside any fixed amount of money for a depreciation fund in bad times, when no profit was being made.'

"If they left the concern (supposing it to be a limited company), as had to be done very often, in the hands of accountants or professional valuers, then the latter would take care that the depreciation fund was provided for, and then it was rather hard for the directors to find the little bit of profit appropriated, or a little more loss made for them, in order to provide for the depreciation fund. At the same time, . . . he thought it was very difficult to lay down a fixed principle of depreciation on collieries."

On the same occasion:

"The President said there was one thing that he never could understand, but perhaps some member present could enlighten him upon the question, and that was the question of a depreciation fund. They saw various statements in the accounts of collieries,—not only of private collieries, but in the accounts of those belonging to public companies. There was, perhaps, a certain sum of money written off, as it was called, for depreciation. He could never find out where the sum that was taken off for depreciation went. Another gentleman* said that the proper place for depreciation (redemption) was to have a reserved fund, and the money so reserved should be invested in consols at 3 per cent. He, however, had never heard of a colliery where there was an investment of that kind. Depreciation was generally a sum that was floating about which was at the beck and call of the company when they wanted money. The proper system would be to put by every year the money—redemption annual fund—into some substantial undertaking where it would be quite certain that it could be recovered when it was wanted.

"The President said the depreciation fund was a thing that went off, and nobody saw anything more of it. Certainly, if there was a depreciation fund, then the sum which was taken off the profits should be invested somewhere. As far as his experience went it was simply mentioned in the accounts, and nothing more was heard of it. It was something like the reserved fund which on one occasion he found on examining the accounts of a large gas company. There was a heading not entitled depreciation, but 'reserved fund.' He asked, as was natural for anybody examining the accounts, where the reserved fund was. In his ignorance of the matter he thought it was invested in some bank or some railway company, but the accountant told him 'the reserve fund is what we carry on the concern with.' Since then he had always had a distrust of a reserved fund, and of the wonderful thing called the depreciation fund."

Here we have the opinion of some of the leading and most important people connected with the mining and metallurgical industries of the British Empire; and it is not too much to say

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* Mr. J. B. Simpson.

that, although it was proved that in usual practice no fund was reserved and accumulated in a bank to redeem capital invested, still the balance of judgment was in favor of such a system.

For reasons broadly stated in the discussion, and other general opinions, members, directors and accountants of public companies would prefer to employ their annual benefit, as is natural, as they pleased, in order to continue a system of re-investing in other shares and in speculation, as has been formerly noted. Besides, there was no law to compel the redemption of capital, and it was "held by the high court of justice in England, in the famous case of Lee *vs.* Neuchatel Company, that it was not obligatory on the directors and shareholders of a company to make any reserve from profits for the purpose of meeting the ultimate loss of the capital which would ensue on the expiring of a lease, or the ultimate exhaustion of minerals."*

There being no law for this object, the questions of prudence and necessity are completely ignored, and consequently there is no attempt to provide for redemption of capital in the form which has been indicated. If, however, such a system were made compulsory, it would tend in a great measure to check immoderate speculation, for it cannot be doubted that, under the system which now rules, many millions of pounds sterling are annually lost.

It is highly probable that in the near future such a law as that indicated may be introduced, and then the question of the practical and proper mode of valuing mines and redeeming capital would have to be considered in the most serious manner at the commencement of every mining undertaking. To-day it is a scientific element entering into every valuation; but then it would become a legally authorized necessity.

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* Messrs. John H. Armstrong and Thomas Harrison, Discussion, North of England Institute of Engineers.

The Geological Features of the Gold Production of North America.

BY WALDEMAR LINDGREN,* WASHINGTON, D. C.

(New Haven Meeting, October, 1902.)

CONTENTS.

I. INTRODUCTION.

THE precious metals, gold and silver, are the basis of the monetary systems of the world. It is, therefore, natural and inevitable that widespread interest should be manifested in their

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production and in the various classes of deposits in which they are contained.

At times a great scarcity of the precious metals has prevailed; at other times the production has seemed so abnormally large that fears have been entertained regarding their ultimate retention as standards of value. Since most nations have adopted the gold standard, and the remaining ones appear likely to do the same in the near future, the question of available supply of gold for the present and future very naturally arises. This necessarily involves a consideration of the characteristics of the gold-deposits.

After the absorption of the gold treasures of the New World by the *conquistadores*, the gold-placers of Brazil and Russia next filled the world's need; later, when these sources of the precious metal began to be exhausted, came the great discoveries of California and Australia, which for a time caused doubts to arise as to the wisdom of maintaining this metal as a standard of value; but from the maximum of output obtained during the early years a steady decline began. The uncertainties as to the amount of gold available for the future were emphatically expressed by eminent geologists and mining engineers.

After an admirable discussion of the gold resources of the world, Prof. Edward Suess, of Vienna, in his book on the *Future of Gold*,* came to the conclusion that there was scarcely any hope of further considerable discoveries, and that the output would gradually decrease, so that the metal would no longer be able to maintain its present economic position.

About the same time, in 1880, Mr. Alexander Del Mar published his *History of the Precious Metals*, and arrived, in the main, at similar conclusions. He believed that not only physical devastation, but moral and political decay follows as the result of gold-mining, and that the total supply of both metals, and particularly of gold, will continue to diminish both in the mines of the Pacific coast and in those of other countries. It seemed to him "but too evident that the future supplies of these metals will not only fail to keep pace with the growth of population and commerce, but that they will absolutely diminish."

There seemed, indeed, to be good reason for such conclusions,

* Die Zukunft des Goldes, Wien, 1877.

for the gold-supply of the world was steadily diminishing and no new sources seemed in sight. But these years proved to be the turning-point, and the production again began to increase, at first, however, very slowly. In 1892 Mr. S. F. Emmons, in a most valuable review of the gold and silver production, came to the conclusion that a further advance in the output of gold was probable; that the annual production of the United States would soon "increase to $40,000,000, and perhaps beyond"; and that the gold production of the world would "increase to $150,000,-000 within a few years, and perhaps to $200,000,000 before the close of the decade."* These predictions have been greatly exceeded by the results of the work of the last few years. The treasures of South Africa and West Australia were found; in Alaska and British Columbia new deposits of wonderful extent were opened; and even in such presumably well prospected countries as Colorado, California, Arizona, Montana and Mexico, new finds were constantly reported, and the production rose steadily and rapidly.

About 1880 the world's annual production of gold was approximately one hundred million dollars; that of the United States about thirty-three millions. In 1900 the gold production of the world had increased to nearly three hundred millions, and that of the United States to seventy-nine millions. While it is true that it is easier to criticise than to predict, it may be pointed out that two principal errors vitiated the conclusions of Prof. Suess and Mr. Del Mar: In the first place the lands of the world were deemed to be so well prospected that no further discoveries were probable; the second error lies in the failure to anticipate the possibility of new processes for gold extraction and the utilization of vast reserves of low-grade ore-bodies.

The figures of the gold production during the last decade may indeed cause hesitation in further predictions as to the available amount of gold. As to ultimate results, it would seem as if we should be justified in concluding, with Prof. Suess, that the gold supply of the world will gradually decrease if no further important improvements are made in the processes for the extraction of this metal; but regarding events so far distant no predictions may safely be made. Regarding the immediate

* "Mineral Resources of the United States," calendar year, 1892, *U. S. Geol. Survey*, Washington, 1893, pp. 90–93.

future, it seems likely that the present production of the world will be sustained, and possibly increased.

The purpose of this paper is briefly to consider the product of each state in North America, emphasizing especially the derivation of the gold from its various classes of deposits, so as to arrive, if possible, at an approximate conclusion as to the relative importance of the different kinds of deposits, and finally to indicate the probable outlook in each state for the immediate future. These calculations have been made possible by the aid of the reports of the United States Mint on the production of the precious metals, the character of which has steadily improved, and which afford a vast amount of important data for the student; and, further, by the reports of the official geological surveys in regard to the economic geology of the states. Much is still lacking, more especially in the knowledge of the age of many deposits, and this paper must, therefore, be considered only as an imperfect first attempt to collect data which are at the disposition of many, but the arrangement of which has not yet, for some reason, been undertaken.

II. Geological Features.

The Gold-Bearing Fissure-Veins.

Practically all the gold output of North America is derived from fissure-veins or from deposits which possess close relationship to fissure-veins. Gold-bearing fissure-veins are in most cases accompanied by placers which are only the result of nature's crushing, concentrating and refining; and these placers may be of different ages according to the date of formation of the vein. Most of them are naturally of Pleistocene (recent) or Tertiary age. For the present purpose the placers will not be considered separately, but *as belonging to the fissure-veins from which they were derived.*

The deposits in fissure-veins are believed to have been formed chiefly by ascending hot waters. The general trend of the testimony indicates that the gold is rather brought up from lower levels than derived from rocks near the surface.

Gold-bearing fissure-veins or equivalent deposits occur in practically all kinds of rocks known on the continent; it is apparently not possible to establish wide-reaching genetic con-

clusions on the basis of the petrographical character of the wall-rock.*

The influence of *locality* is much stronger. Gold-bearing veins cluster in certain localities. A critical examination will reveal the fact that many vein-systems are massed about the contacts of intrusive masses, which consolidated far below the original surface of the earth at the time of the igneous activity, and which have been exposed by subsequent erosion. Most commonly, perhaps, these intrusive rocks are diorite, monzonite, quartz-monzonite, granodiorite, or their porphyries, more rarely typical granites. Under favorable conditions it can often be proved, and in other cases established with probability, that the upper part of the vein has been removed by the same erosion which laid bare the intruded rock masses. In other words the top of the vein has been removed, the root remains. It seems plausible that in these cases the igneous intrusion was one, perhaps the principal, of the genetic causes. Dynamic action producing fissures in and about the intrusives is another genetic cause. The age of these veins must in general be considerable, for the great erosion involved has usually required a long time-interval.

Another large class of vein-systems cut the recent or comparatively recent lavas, which cover the surface of the older, eroded rocks in the form of successive volcanic flows. Frequently the age of these lavas may be established with accuracy. From available data we may be enabled to determine the approximate level of the surface of the earth at the time the last flow was erupted; and, in the case of veins cutting this series, we are enabled to say with certainty that a given part of the vein was near the original surface of the earth existing at the time of vein-deposition. This given part may, then, be said to be the top or the true apex of the vein.

It is true that there are very many cases in which we cannot determine with certainty, or even with probability, at what vertical distance from the part of the vein under discussion the original surface of the earth, at the time of vein-formation, was located. But this does not diminish the force of the argument in the two principal divisions discussed. There are certainly

* This point has recently been emphasized by Mr. W. H. Weed in his paper on the "Influence of Country-Rock on Mineral Veins," *Trans*. xxxi., 634.

few gold-bearing districts on the continent which do not occur either near or in intrusive masses, or in or near volcanic flows. In districts of igneous activity the effusion of surface lavas is generally accompanied by the intrusion of bodies of magma far below the surface, which, owing to physical conditions, consolidates as granular or coarsely porphyritic rocks. This has actually been shown in many volcanic districts which have been deeply and rapidly dissected by erosion. In rare cases we may even trace the vein from the top in the effusive lavas down to the root in intrusive rocks. It may, therefore, be concluded as most probable that the two classes of veins described above are really of the same kind: that the roots reached up through once overlying, now eroded, lavas, and that the tops generally may be traced through the lavas to the vicinity of the intruded masses.

The question whether any difference exists in mineral composition and metasomatic alteration between the tops and the roots of veins is a most important one, but it cannot be definitely answered in the present state of our knowledge. There are arguments *pro* and *con*. Prof. De Launay answers the query in the affirmative, and many of his arguments have great force. This much is certain: that in many cases of gold-quartz veins differences of up to 4000 feet in elevation have little influence on the minerals and vein-matter, while in some cases, and chiefly with smelting-ores rich in silver, distinct changes in mineral composition appear in depth, which would seem to be independent of secondary alteration or enrichment.

Fissure-veins carrying gold have certainly been formed at various times in the geological history of the continent. Cambrian conglomerates bear witness to pre-Cambrian gold-veins, and very recent thermal deposits at Steamboat Springs, Nevada (according to Becker), and at Boulder, Montana (according to Weed), prove that gold is deposited by thermal waters to-day. But the process has evidently not been a continuous one. Cambrian, Silurian, Devonian and Carboniferous gold-deposits are not definitely known to exist in North America. Continuous sedimentation, absence of dynamic movements and relatively slight igneous activity characterized these periods.*

* Igneous rocks of Paleozoic age are found at various places along the Sierra Nevada, British Columbia and Alaska. If Paleozoic gold-deposits are found on this continent, it will probably be along this line.

The great eruptions of the Cordilleran belt of North America began during the Triassic period of the Mesozoic age, and igneous activity has continued almost without interruption from that date to recent time. Each eruption has probably been accompanied by more or less extensive deposition of gold in fractures near the igneous focus. On the Pacific coast the eruptions began at an earlier date than in the region of the Rocky Mountains; and, likewise, many of the gold-deposits of the Pacific coast antedate those of the Rocky Mountains. In the latter province the igneous rocks began to break out at the close of the Cretaceous period, and have continued at least up to the beginning of the Pleistocene. Certain periods of deposition, however, stand out prominently, and we may with good reason separate the distinctly Cretaceous or late Mesozoic gold-belt of the Sierra Nevada and the Pacific coast in general from the Tertiary, mostly post-Miocene, veins so extensively developed in Mexico, Nevada and Colorado. The former are genetically connected with great intrusions of granitic and dioritic rocks, the latter with big flows of surface-lavas which erosion has not, as yet, removed. But both in the Great Basin and in the Rocky Mountains there are also many deposits of late Cretaceous or early Tertiary age genetically connected with intrusions of granitic rocks and, very commonly, porphyries. In very many cases the age of these deposits is doubtful. If erosion has been exceptionally active in the particular district in which they occur, they may well, though occurring in connection with deep-seated intrusions, be of Tertiary age. To this class of doubtful age belong, for instance, many of the gold-veins of Montana. Miocene and later igneous rocks are often lacking in this region, so that an accurate determination of age becomes very difficult.

Still another complication to be borne in mind consists in possible, though probably rarely occurring, re-opening of veins and superimposition of deposits of two or several epochs. All this being admitted, there still exists, in my opinion, sufficient reason for attempting a division of the deposits according to age. It is readily acknowledged that this first attempt is imperfect, and that future researches will probably bring many changes in the divisions here tentatively set forth.

The next question is whether there is any notable difference,

in mineral constituents and metasomatic alteration, between deposits of various periods. The mineral vein is the result of two variable factors: the composition of the mineral waters and the conditions at the time of deposition. Is there any definite gradual change in both or either of these factors by which the older deposits can be distinguished from the younger?

The question of depth below the original surface has already been touched upon, and in considering the present problem it is necessary to deal with those parts of deposits of various ages which were formed at the same distance from the original surface. A definite answer is difficult because the older deposits are usually more deeply eroded than the recent ones. *A priori*, however, there seems no reason why a difference should exist, for mineral waters of as many different kinds of composition as are seen to-day have probably always reached the surface, and the conditions of deposition at corresponding levels and under corresponding circumstances have probably always been about the same.

Looking over the field, it is undeniable that within many belts of gold-deposits of contemporaneous origin the veins are very similar in mineral composition and metasomatic development. The Appalachian belt of gold-quartz veins contains deposits of striking similarity from one end to the other. The Mesozoic gold-quartz veins of the Pacific coast are practically identical in character from Lower California to Alaska, and, moreover, closely related in character to the far older Appalachian belt. Where the wall-rocks were easily altered, they contain abundant calcite and other carbonates, besides much sericite. This points, without doubt, to a remarkable constancy throughout the whole province in the composition of the mineral waters which formed the veins. They were manifestly distinguished by an abundance of alkaline carbonates. On the other hand, scarcely one of the veins, which in so many parts of the Cordilleran region cut volcanic flows of Tertiary age, can be classed as identical with the Pacific coast type of gold-quartz veins. While it is perhaps not permissible to say that they represent one type, yet most of them have certain common, peculiar features, constituting a relationship. They frequently contain both gold and silver; the gold is finely divided, and rarely accumulates below the veins in such rich placers as are found as-

sociated with the Pacific coast type of gold-quartz veins; the metasomatic alteration is generally propylitic; that is, accompanied by the formation of chlorite, epidote, and, near the veins, of sericite and kaolin, while the extensive carbonatization found near the California gold-quartz veins is usually absent. The mineral-waters accompanying the Tertiary eruption certainly differed on the whole, and notably from those of other eruptive periods, and were apparently lacking in alkaline carbonates. Prof. Suess recognized this type long ago, basing his conclusions largely on von Richthofen's work. Prof. Vogt has more recently insisted on its importance. There are several types of these Tertiary veins, and it is perhaps not advisable, as I have done in a preliminary note on this subject, to retain the name *propylitic* for the whole group, as some of them do not show this alteration in typical form.

In conclusion, it may be said that gold-veins of the same age and province usually have the same characteristics. Belts of different age may differ greatly in general features. This is probably due to the varying composition of the mineral waters following different periods of eruption.

Possibly, as suggested above (p. 797), the depth below the original surface may have something to do with this question, as the older veins are usually deeply truncated by erosion, and a gradual change in the character of the thermal waters may have taken place during the upward passage of the solutions. More likely, however, the principal cause is a radical difference in the composition of the waters throughout the province.

In comparing different veins with a view to the elucidation of this problem only those having country-rock of similar general character should be selected, for it is well known that the composition of the wall-rock may have great influence on the metasomatic processes, and hence on the composition of the vein.

Contact Metamorphic Deposits.

The preceding remarks apply exclusively to fissure-veins and the closely related irregular deposits in which the gold was deposited by heated waters, which, as a rule, probably came up from below.

There is another source of gold in the so-called contact metamorphic deposits formed at or near the contacts of intrusive

granitic or porphyritic rocks. The characteristic mineral associations (ordinarily garnet, epidote, vesuvianite, ilvaite, magnetite, specular hematite and sulphides) of these deposits are such that they are probably best explained as the products of the action of water above the critical temperature. This water is believed to have been given off from the hot magma, and to have been accompanied by metallic compounds, sulphur, etc., also probably above their critical temperatures. Under these conditions,—that is, a temperature of not less than + 365° C., and a pressure of not less than 200 atmospheres,—water can only exist as a perfect gas. Minerals formed under such conditions are known as of pneumatolytic origin.

When the temperature sinks below this limit the water, if under sufficient pressure, remains an ordinary fluid, and the deposits formed by it appear to undergo a change. To such conditions the deposits of ordinary fissure-veins should probably be attributed.

Finally, under conditions of high temperature and slight pressure very near the surface, water, as well as other compounds, may be converted into a vapor, and such deposits as may be formed by this action are said to be due to sublimation. Escaping gases from heated rocks near the surface in volcanic districts are called fumaroles. The name of fumaroles or fumarolic action is sometimes applied to contact metamorphic deposits, but this usage appears to me to be incorrect.

Contact metamorphic deposits occur in the United States, as well as in British Columbia and Mexico. Ordinarily, copper sulphides and magnetite are the principal ore-minerals, but they may carry a small quantity of gold. A certain small amount of gold has been derived from these deposits in the United States and British Columbia; just how much is very difficult to decide. In Mexico contact metamorphic deposits are more common, and sometimes contain much gold. It is probable that over one million dollars has been obtained from this source in Mexico; but here, again, exact figures are unobtainable.

Classification According to Age.

Introduction.—In stating the production of gold in the various states, it is necessary to adopt some unit for its measurement. The one selected is one million dollars; this unit will be indi-

cated by M²$*. In this manner the results will be much more clearly presented than by long series of figures. The most scientific way to express the product is doubtless in kilograms; but for the present purposes the adopted unit seems much more tangible and more easily understood.

From the Atlantic to the Pacific ocean, the mountains of North America contain gold, although the largest treasures are stored in the great ranges of the Cordilleran region. From the time of discovery up to 1900 the United States has produced about M²$2529, Mexico at least M²$200, and possibly twice as much, and British North America M²$140, making a grand total of M²$2869. This great product is divided among primary veins of pre-Cambrian, Mesozoic and Tertiary age. To separate the last two groups is in many cases a difficult matter.

Pre-Cambrian Deposits.—Gold was discovered in veins of the older rocks of the Appalachian Mountain region about one hundred years ago, in Georgia, the Carolinas, Tennessee, Maryland, Virginia, and even farther north. Poorer deposits of the same kind have been found up to the Canadian line, and north of this richer gold-veins occur again in Quebec, Ontario and Nova Scotia. Again, farther westward in the United States, in Michigan, probably pre-Cambrian gold-quartz veins occur on a smaller scale. Still farther west they are developed in the Black Hills of South Dakota, and also in Wyoming. The last two are the only localities in the Cordilleran region in which pre-Cambrian deposits have been recognized.

The primary deposits in the above-mentioned districts are chiefly gold-quartz veins with free gold and auriferous sulphides. The veins were probably to a large extent formed before the Cambrian period, and are thus the most ancient deposits of the continent. Among the evidence pointing directly or indirectly to this conclusion, the following have especial weight: The Triassic sandstones of the Atlantic coast contain placer gold; no important gold deposits are found in the Paleozoic rocks of the Appalachian region; Carboniferous conglomerates in Nova Scotia are said to contain water-worn gold of older veins; in the Black Hills the Cambrian conglomerates yield placers of the precious metal. During the 19th century

* For example, M²$1.0 = $1,000,000. M²$2.25 = $2,250,000. M²$0.5 = $500,000, etc.

the Southern states produced $\mathrm{M}^2\$47.0$, Nova Scotia and adjacent provinces $\mathrm{M}^2\$17.0$; during the last ten years the Southern states have yielded $\mathrm{M}^2\$0.3$ and the eastern Canadian provinces from $\mathrm{M}^2\$0.5$ to $\mathrm{M}\$^2 1.0$ per annum. The deposits are not rich according to our standards for the Cordilleran region, but the yield is steady, and can probably be relied upon for many years to come.

Economically, the most important pre-Cambrian deposits are found in the Black Hills. The old pre-Cambrian schists here contain fissure-veins and seam-belts of free-milling gold-ores covered by Cambrian sandstones containing placer-gold. These deposits are worked on a large scale; they have yielded, since discovery in 1876, about $\mathrm{M}^2\$74.0$, and produce annually $\mathrm{M}^2\$3$ or $\mathrm{M}^2\$4$.

Altogether, then, the pre-Cambrian deposits have given us, since discovery, $\mathrm{M}^2\$138.0$. In most cases extensive erosion has taken place since these veins were formed, and the surface of the land at the time of their formation must in some cases, at least, have been thousands of feet above the level at which they are worked at present. They are the "roots" rather than the "tops" of veins.

Cretaceous Veins of the Pacific Coast.—The most important gold-belt in North America extends along the Pacific coast. It is throughout characterized by quartzose ores with free gold and auriferous sulphides. A great erosion has taken place since the veins were formed; and here, too, as in the pre-Cambrian deposits, we have to deal with the lower parts of veins, the upper parts having generally been removed in many places to the extent of thousands of feet.

Beginning in Lower California, Mexico, a hundred miles or more south of the boundary line, this great belt continues through San Diego, Los Angeles and Kern counties; through the central part of California, where it is developed in great strength; then on to Northern California, southwestern and northeastern Oregon and Idaho. In the latter States it is modified by the appearance of many silver-gold deposits and veins carrying auriferous sulphides without free gold. Covered for a distance by the lava-flows of the Cascades, it again appears in southern British Columbia—on Vancouver Island, among other places. Strong development is again attained in the Cariboo district, in

central British Columbia, and it continues through the Omineca, Cassiar and Atlin districts to the Klondike region. Thence, bending westward, it follows the Yukon to the western end of the continent at Nome, on the Seward Peninsula.

The Cretaceous age of this belt is clearly established in California. In Oregon and Idaho a late Mesozoic age is extremely probable. In British Columbia and Alaska the evidence is not so positive, and the deposits may possibly, in part, be older.

Throughout this immense stretch of country the veins are accompanied by a great development of placers. Placers are, indeed, characteristic of this class of gold-veins, and by far the larger part of the yellow metal has been obtained from them. At many places in California, as well as in Oregon and Alaska, the veins from which these placers were derived have been very disappointing, the fact being that the primary deposits are often scattered in many little seams rather than concentrated in great veins.

California alone has yielded M^2\$1380.0 from this belt; Oregon M^2\$54.0; British Columbia and Northwest Territory M^2\$123.0; Alaska M^2\$30.0. The total is over M^2\$1700.0. During 1900 the belt probably yielded M^2\$54.0, of which one-half came from British Columbia and the Yukon. This represents a great increase compared with the figures of ten years ago, and it is doubtful whether this increase will be maintained. At least M^2\$27.0 was obtained from the placers on the Yukon and in Alaska. If no further great discoveries are made in this region, our knowledge of placers forces us to the belief that this last figure will gradually decrease. Quartz-mining will to some degree compensate for this; but the quartz-mines have usually, in the older districts, yielded less than the corresponding placers. California's output will doubtless be maintained at about the present figure for many years.

Late Cretaceous or Early Tertiary Deposits (Central Belt).—Besides the Pacific gold-belt, there is a broad zone in the central and eastern part of the Cordilleran region which contains an abundance of gold-deposits of varying character. Many of these seem to have been formed a little later than the California gold-quartz veins, perhaps largely at the very close of the Cretaceous, or possibly at the very beginning of the Tertiary period.

This broad zone begins in Mexico, where the Pacific states of Sonora and Sinaloa contain many gold-veins in pre-Cretaceous sediments, granites and crystalline schists. According to Prof. Dumble, many of the Sonoran deposits occur in Triassic rocks, and are considered by him to be of the same age as the California veins. Similar veins in old rocks continue through the southwestern part of Arizona, but their age is not definitely known. Many of them are important producers.

Although undoubted Tertiary deposits prevail in Nevada, those of an older period are probably not absent. A few of them are free-milling gold-quartz veins, but in the majority the ores consist chiefly of sulphides alone, and the value of the silver exceeds that of the gold.

In Utah the principal gold-mines are those of the Mercur district, in which ores suited to the cyanide process occur in limestone close to intrusive sheets of porphyry. These yielded over M²$2.0 in 1900. Most of the remaining amount credited to Utah is derived from gold-bearing silver-ores of the smelting class, which are found in veins and irregular deposits in sedimentary rocks close to bodies of intrusive (Cretaceous?) porphyries. The future of the gold production is here very closely connected with the vicissitudes of the silver and copper markets.

In Colorado the most important Cretaceous gold-deposits are those of Leadville. Here, again, the ores occur in Paleozoic sediments and porphyry; and the gold production, small until a few years ago, reached M²$2.7 in 1900.

In Idaho and Montana late Mesozoic and early Tertiary veins are developed on a large scale. We note here the interesting fact of a junction with the Pacific belt, through northeastern Oregon and central Idaho, into Montana. Going eastward, the free-milling and quartzose character is partly maintained, but silver becomes more prominent in the ores, and auriferous sulphide ores often replace the native gold. Central Idaho formerly contained many rich placer-camps, which have yielded their millions. As in Oregon and in Montana, the first years of mining were largely devoted to working this form of deposit. Bannack, Alder Gulch, Helena and Confederate Gulch are well-known names of celebrated placer-camps in Montana. The great producing quartz-mines are not, however, those from

which the placers have been derived. They contain much silver, and pan-amalgamation is the most common process.

After the exhaustion of the placers, silver-ores of the smelting class containing galena and other sulphides, together with a little gold, were also extensively mined. This industry has declined during recent years; but, as a partial compensation, at least M²$1.0 per annum is obtained as a by-product from the smelting of the copper-ores of Butte.

The majority of gold-bearing veins in Idaho and Montana are genetically connected with the intrusion of very large bodies of granitic rocks during the Cretaceous period. This explains the fact of relationship with the Pacific gold-belt, for there, too, the veins stand in undoubted causal connection with the great Mesozoic granitic "batholiths," as the large intrusive bodies are called. As far as we know, these batholiths are either absent or only developed on a small scale in Nevada, Utah and Arizona.

In the southern part of British Columbia are a number of veins which contain copper-gold ores, and to less extent milling ores, and which are believed to belong to the late Mesozoic period. They are chiefly found in diorites and allied intrusive rocks.

Looking at this central Mesozoic gold-belt as a whole, it is believed that, north of Mexico, it has produced at least M²$286.0 since discovery, and during 1900 its tribute to the total of North America was about M²$14.0.

In this chain of deposits the gold production is closely associated with the silver and copper industry, for sulphide ores prevail over those containing native gold. No wonderful increase of production may be expected, but rather a steady maintenance, and possibly a gradual growth if there is no serious decline in the values of copper and silver. Placer-mining, with its dwindling tendency, is still represented in Montana and Idaho; in the other States of this belt it plays a comparatively insignificant part.

Tertiary Deposits.—A fourth and last class of gold-producing veins are of Tertiary, mostly post-Miocene age. They are usually found in regions of intense volcanic activity cutting across heavy andesite flows, more rarely rhyolite and basalt. In many cases these veins may be seen to continue down into

the underlying floor, upon which the volcanic flows were poured out, and which may be of igneous or sedimentary character. Sometimes, indeed, an active erosion has removed much of the volcanic flows, and the veins crop directly in older rocks.

The majority of these veins in Tertiary lavas have certain common and persistent characteristics and form a fairly well-defined class, usually called *propylitic veins*, alluding to the peculiar alteration of adjoining rocks which seems to characterize them. The ores are nearly always quartzose, and sometimes contain silver alone; more rarely gold alone; but most commonly both gold and silver in about equal quantities by value.

They are often characterized by great richness, the word "bonanza" being employed to represent their big ore-shoots. While some of these veins yield steady and reliable products, many of them burst out in sudden blazes of glory like shooting stars, only to be extinguished with equal suddenness. The gold is nearly always in such peculiarly fine distribution that extensive and rich placers are rarely formed from them; contrasting, in this respect, with conditions in the Pacific gold-belt. Many of them, in districts of great erosion, show that the values continue in depth; but the ore is perhaps less rich than in those parts formed nearer to the original surface. In this class we evidently have to do with the part of the vein which was not far from the original surface at the time of ore-deposition. In some cases the ores can be proved to have been formed but a few hundred feet from this surface. Instead of roots of veins, as in the Pacific and Appalachian belts, the propylitic veins ordinarily represent the uppermost part of the area of deposition along the fissure. Not all of the distinctly Tertiary veins possess, however, the character of typical propylitic veins. Many deviate considerably, but few, if any, show the typical development of gold-quartz veins of the Pacific coast.

This belt of Tertiary veins is most extensively developed in Mexico. The central plateau contains the great silver-veins of this class, which always contain a small amount of gold, and from which the greater part of Mexico's gold output has been derived. But along the western slope of the Sierra Madre in

Chihuahua, Zacatecas and Sinaloa heavy andesite flows contain gold-silver veins of great importance, and are, together with the veins of the older belt in Sonora, largely responsible for the greatly increased gold production of Mexico.

Entering the United States, Tertiary veins are found in Arizona and New Mexico. In Arizona, probably both Cretaceous and Tertiary veins occur, and in the present state of our knowledge their separation is sometimes difficult. The Commonwealth mine in Cochise county is a prominent representative of the younger veins; it breaks through rhyolite, and is at present one of the largest producers of the territory. One-third of the value is in gold, and the rest in silver.

In New Mexico are several districts containing these veins—chiefly, it is said, in andesitic rock; but the output of this territory has not as yet reached the million-dollar mark.

The development of Tertiary veins continues northward into Nevada and California. San Bernardino county, in California, contains silver-deposits in rhyolite, and probably, also, Tertiary gold-veins. Veins of similar kind continue along the eastern foot of the Sierra Nevada as far north as Alpine county, and become most productive in Mono county; the mines at Bodie, in andesite, produced in nine years $M^{2}\$12.0$ in gold, besides much silver.

Northward from this point few Tertiary veins are found, though intense volcanic activity prevailed in the Northern Sierra Nevada and the Cascades during the Tertiary. At one or two places in Oregon, chiefly in the Bohemia district in the Cascade Mountains, the volcanic rocks contain gold-veins, but they have not as yet yielded much. Continuing northward into Washington, the Monte Cristo veins, in andesite and diorite, represent this type, but are not credited with extraordinary production.

No veins of this class are thus far known in British Columbia or the Northwest Territory, but on the southern coast of Alaska we meet sporadic cases again. The Apollo mine, on Unga Island, breaks through andesite, and has produced gold for the last few years to a maximum annual amount of about four hundred thousand dollars. The Alaskan peninsula also shows evidence of more recent Tertiary mineralization.

Returning southward to Nevada, this class of gold-deposits is abundantly represented. The Comstock vein, Tuscarora, Eureka, Tonopah, the De Lamar veins, are known or believed to be of propylitic character, and, with the exception of the latter, occur in volcanic rocks. The Comstock easily leads, with an estimated production of over M^2\$148.0 in gold, and the other districts have contributed heavily to the total output, although all also contain much silver in their ores. The production of Nevada has fluctuated greatly, and after long decline is again increasing.

A line of Tertiary veins continues northward from Nevada into Idaho. In the southern part of that State they are represented by the Owyhee gold-silver mines, which since their discovery have yielded M^2\$12.0 in gold; and farther north by the bonanzas of Rocky Bar, Atlanta and Custer, which, probably, should be referred to this type. Still farther north is the Thunder Mountain district, which, if reports are reliable, contains gold in rhyolite. No Tertiary primary gold-deposits have been reported north of this point.

Veins of this class occur in Utah,—for instance, at the Horn-silver-mine and at Tintic; but these deposits carry very little gold.

Returning now to New Mexico, a belt of these veins continues northward into Colorado and reaches a development not known elsewhere, except in Mexico. The total output of Colorado is probably about M^2\$250.0. In 1900 the output was M^2\$28.8. Excepting the Leadville deposits, the principal gold-producing districts are of Tertiary age. Oldest among them as to discovery are the veins of Gilpin, Boulder and Clear Creek counties, which crop in Archean rocks and are accompanied by andesite dikes. These districts have been remarkably steady producers since 1859, and contribute annually about M^2\$3.0. They promise to continue their production for a long time. Another important locality is the San Juan district, in southwestern Colorado, where strong quartz-veins cut heavy andesitic flows. The yield has increased greatly since 1890, and in 1900 reached M^2\$4. It promises well for the future; and some of the mines, like the Camp Bird, have proved veritable bonanzas. The output will probably continue to increase for some years. An interesting feature of the San Juan region is that in some districts which

have suffered great erosion the veins are found to continue into bodies of intrusive diorites and porphyries of later age than the andesites, thus offering a comparison of conditions near the original surface and at a considerable distance below it.

Finally, there is the great Cripple Creek district, which has yielded M^2\$77.3 during the period 1892 to 1900 inclusive, and in 1900 produced M^2\$18. A network of veins occurs in andesite, phonolite and underlying granite, and has thus far chiefly carried telluride ores. What may be expected of this district in the future is a most important question, and one not easy to answer.

North of Colorado the propylitic deposits are almost absent, though they appear in sporadic form in Montana.

Roughly calculated, about M^2\$564.0 has been contributed by the propylitic veins to the total gold output of the United States, to which should probably be added at least M^2\$160.0 from Mexico. For 1900 we may estimate M^2\$36.0 as the output of these veins in the United States, and perhaps M^2\$7.0 in Mexico.

Conclusions.

Summing up the data obtained, we should estimate as follows:

Source of Production of Gold in North America.

	Total M^2\$.	1900 M^2\$.
Pre-Cambrian,	139.0	5.0
Cretaceous (Pacific),	1719.0	54.0
Cretaceous and early Tertiary (Central),	287.0	14.0
Tertiary (largely propylitic),	724.0	43.0
	2869.0	116.0

The great increase in the gold production of the continent during the last ten years has been due, *first*, to important discoveries of new districts in almost every producing State; *second*, to the increased activity in many old gold-districts and mines; *third*, to the late great development of copper-smelting, by which much gold has been obtained as a by-product; *fourth*, to the introduction of the cyanide process, rendering many classes of low-grade ores and tailings available; and, *fifth*, to the introduction of hydraulic elevators and dredgers, giving a new lease of life to many old and decaying placer-camps.

Many considerations suggest that the increase will probably

TABLE I.—*Gold Production of North America.*

Unit: $M^2\$ = \$1,000,000$.

Divisions. United States.	Total from Discovery to 1900, incl. M²$	1877-1900, incl. M²$.	M²$. 1900.	1901	1902.*
Alaska	30.7	30.7	8.2	6.9	7.8
Arizona	42.1	33.6	4.2	4.1	4.2
California	1380.0(?)	351.1	15.8	16.9	17.1
Colorado	251.1(?)	204.3	28.8	27.7	27.5
Idaho	112.8	42.8	1.7	1.9	2.1
Montana	203.5(?)	83.6	4.7	4.7	4.1
Nevada	250.0(?)	99.7	2.0	3.0	3.5
New Mexico	17.6	13.3	0.8	0.7	0.7
Oregon	54.5	29.7	1.7	1.8	1.9
South Dakota	90.0	89.4	6.2	6.5	7.4
Utah	27.0	24.1	4.0	3.7	3.7
Washington	21.4(?)	8.9	0.7	0.6	0.4
Wyoming	1.0(?)	1.0	1.0	....	....
Appalachian States (Mainly Georgia and the Carolinas.)	47.0	8.0	0.3	0.2	0.3
	2528.7	1020.2	79.2	78.7	80.7
British North America.					
Nova Scotia	13.7	9.7	0.6	0.5	....
Quebec	2.0(?)	0.2	....	....	....
Ontario	1.2(?)	1.1	0.3	0.2	....
British Columbia	70.7	21.1	4.7	5.3	....
N. W. Territory	52.6	52.6	22.3	18.0	14.6
	140.2	84.7	27.9	24.0	....
Mexico	200.0(?)	66.5	9.0	10.3	....
Total	2868.9	1171.4	116.1	113.0	....

NOTE TO TABLE I.—This table has been compiled chiefly from the Mint Reports of the United States. Regarding the United States, accurate statistics date from 1877; the first column, showing the total production of each State is, to a great extent, based on estimates of the output of early placer-mining, by J. Ross Browne, R. W. Raymond, and the Mint Bureau. The figures given for California, Nevada, Montana, Washington, Oregon and Colorado are especially uncertain. The total ($M^2\$2528.7$) exceeds the estimate of the Mint Bureau by nearly $M^2\$150.0$, though the two calculations are probably based on the same evidence. If the results of the Mint Bureau are accepted as correct, the figures given in the first column are too high; but how and where the correction should be applied is very difficult to say. In most States, however, the figures in the first column will be considered too low, locally current estimates being much higher.

The figures for British North America are probably fairly correct, but those from Mexico are admittedly only estimates by the Mint Bureau or by other statisticians.

* Preliminary estimate by the Director of the Mint.

TABLE II.—*Tentative Distribution of Gold Production of North America According to Age of Primary Deposits.*

Unit: M²$ = $1,000,000.

Divisions. United States.	Distribution of Total Production. From Discovery to 1900, incl. M²$. Pre-Cambrian.	Mesozoic (Pacific Coast Belt).	Late Cretaceous or Early Tertiary (Central Belt).	Tertiary (Mostly Post-Miocene).	Distribution of Production of 1900. M²$. Pre-Cambrian.	Mesozoic (Pacific Coast Belt).	Late Cretaceous or Early Tertiary (Central Belt).	Tertiary (Mostly Post-Miocene).
Alaska	......	29.7	......	1.0	......	7.8	......	0.4
Arizona	......	22.1	......	20.0	......	......	2.0	2.2
California	......	1350.0	......	30.0	......	14.8	......	1.0
Colorado	......	......	34.0	217.1	......	......	2.7	26.1
Idaho	......	90.0	......	22.8	......	0.7	......	1.0
Montana	......	......	200.0?	3.5?	......	......	4.7	......
Nevada	......	......	20.0	230 0	......	......	?	2.0
New Mexico	......	......	7.6?	10.0?	......	......	0.4	0.4
Oregon	......	54.0	......	0.5?	......	1.7	......	......
South Dakota	74.0	......	......	16.0	3.8	......	......	2 4
Utah	......	......	25.0	2.0?	......	......	4.0	?
Washington	......	10.0	......	11.4	......	0.2	......	0.5
Wyoming	1.0	......	......	......	0.1	......	......	......
Appalachian States (Mainly Georgia and the Carolinas.)	47.0	......	......	......	0.3	......	......	......
	122.0	1555.8	286.6	564.3	4.2	25.2	13.8	36.0
British North America.								
Nova Scotia	13.7	......	......	......	0.6	......	......	......
Quebec	2.0?	......	......	......	......	......	......	......
Ontario	1.2?	......	......	......	0.3	......	......	......
British Columbia	......	70.7	......	......	......	4.7	......	......
N. W. Territory	......	52.6	......	......	......	22.3	......	......
	16.9	123.3	......	......	0.9	27.0	......	......
Mexico		40.0?	......	160.0?		2.0?	......	7.0?
Total	138.9	1719.1	286.6	724.3	5.1	54.2	13.8	43.0

NOTE TO TABLE II.—It should be expressly stated that this table is only a first tentative estimate, as in very many cases the data for exact subdivision are not available. The distribution for 1900 is, of course, probably more nearly correct than the segregation of the total product attempted in the first part of the table.

not continue in the same ratio for the next few years, providing that no great discoveries are made of new placers in the far north or of vein-systems like that of Cripple Creek. The greater part of the increase has been derived from the northern placers and from Cripple Creek; in 1900 the gold derived from these sources amounted to M²$46.0. Subtract this from a total for North America of M²$116.0, and only M²$70.0 remains.

The placer-fields now known in Alaska and Northwest Territory will in all probability gradually decrease their output during the next few years. Many reserves of old mill-tailings and dredging-grounds to which new processes have been applied are being rapidly exhausted. Some districts producing gold from copper-ores and others working bonanzas of the Tertiary veins will not improbably lessen their output. Against this stand always the possibility of new discoveries and the introduction of improved processes. Tentatively striking a balance, a small decrease of the gold production of North America would seem more likely, for the next few years, than an increase.

III. Detailed Descriptions.

The United States.

Statistics.—Previously to 1848 the annual production of the United States rarely exceeded M²$1.0. Subsequently to that date, the California discoveries raised the figures by leaps and bounds, and the maximum of M²$65.0 was attained in 1853, gradually declining to M²$39.2 in 1862. The discoveries in Montana, Idaho and Oregon brought the figures up to M²$53.2 in 1865, when a long decline began to M²$33.4 in 1875. Again the output increased to M²$51.2 in 1878, this being largely due to the Comstock bonanzas. Then declines were again resumed down to a minimum of M²$30.0 in 1883, from which point an increase of M²$7.0 or 8.0 per annum has carried the output up to a maximum of M²$79.0 in the last year of the century.

During the early days of mining in the Western States, particularly in California, Oregon, Idaho and Montana, almost the whole production was obtained from placers. By far the largest part of the total production of the United States since 1848 is formed by placer-gold. This has gradually changed, so that, at present, in all the States and territories, excepting Alaska, placer-gold forms but a small fraction of the production. For many years past the output of placer-gold has steadily dwindled, but since 1898 a considerable increase has appeared, due largely to the new discoveries in Alaska, but also to the activity in dredging old, partly worked-over deposits and tailings in California, Idaho and Montana. The following table, based on figures in the Mint Report, exhibits the production of gold from placers and lodes in the United States:

Year.	Lodes. $M^2\$$.	Placers. $M^2\$$.
1897	50.0	7.4
1898	57.0	7.4
1899	62.1	9.0
1900	67.2	12.0
1901	66.0	12.2

Alaska.

Statistics.—Alaska entered the list of gold-producing regions about 1880, with a moderate figure of a few thousand dollars. The production increased gradually, and in 1892 the million-dollar mark was reached. In 1897 this had risen to $M^2\$2.4$, in 1899 to $M^2\$5.5$, and in 1900 to $M^2\$8.2$. The total gold production of Alaska is believed to be $M^2\$30.7$.

Geological Features.—The principal primary gold-deposits appear to be of Mesozoic age or older, and should be considered as the continuation of the deposits of California, Oregon and British Columbia. Besides, there are, at a few places along the southern coast and in the Alaskan Peninsula, indications of a second period of mineralization of Tertiary age.

Along the southeastern coast extends an important belt of quartz-veins, worked at Berner's Bay, Douglas Island, Juneau, Silver Bow Basin, and Cook's Inlet. The principal producing point is Douglas Island. The veins occur in older rocks, slates, schists and granites, and contain chiefly free-milling gold-ores with auriferous pyrite. Placers accompany the veins at some points, as at Juneau and Cook's Inlet, but the recent glaciation has in most cases swept away the detrital accumulations.

The mines on Douglas Island are heavy producers. The output began in the early eighties, and rose rapidly from a few hundred thousand dollars to nearly $M^2\$2.0$ in 1900. Dr. Becker regards it as probable that the Douglas Island deposits are of Mesozoic age.

Placers have also been worked recently in the Porcupine district near Skagway and in the Copper River region. The Chistchima placers in the Copper River country, according to an oral communication from Mr. W. C. Mendenhall, have been derived from stringers in slates of Permian age. The primary deposits are post-Permian and pre-Eocene.

The second great gold-producing region is that of the Yukon,

continued in a westerly direction towards Cape Nome, on the Seward Peninsula. The deposits are chiefly placers, and yielded only moderately (up to M²$1.2 per annum) before the recent Cape Nome discovery.

From data by Spurr, Brooks and Schrader, the placers were doubtless derived from veins in considerably altered sedimentary rocks found in the vicinity, called the Birch Creek, Forty Mile and Rampart series. These are of Paleozoic age, in part certainly Silurian. The age of the primary deposits is thus largely post-Silurian; and, as the placers are regarded as Pliocene, also pre-Pliocene. Most probably these veins are Mesozoic, and of the same general period as the California deposits, but the possibility is not excluded that they may be older. At Cape Nome, and on the Seward Peninsula generally, the rich placers are derived from normal gold-quartz veins occurring in much altered strata of Paleozoic, possibly also, in part, Mesozoic rocks, connected with intrusive granites and greenstones.

In Alaska, as in Idaho and parts of Oregon and California, the quartz-veins are often disappointing, the evidence being that the placer-gold has been derived rather from stringers and veinlets than from larger veins.

A more recent propylitic mineralization is noted from the Alaskan Peninsula by Spurr, who finds that on the Skwentna and the Kuskokwim, as well as in the Tordrillo Mountains, gold-deposits are associated with dikes of Eocene age. Still more recent are, perhaps, the important gold-silver veins on Unga Island. As described by Becker, they occur in andesite, and are typically propylitic.

Distribution.—Almost the whole of the gold production seems to be originally derived from the Mesozoic (or older) gold-quartz deposits. Only a fraction (M²$0.4 in 1896) is thus far to be credited to the Tertiary propylitic veins. As the total production was only about M²$2.0 that year, it was, however, almost one-quarter of the production.

In 1897 the placers yielded M²$0.65, the lodes M²$1.7; in 1899 the placers had increased to M²$3.1, the lodes to M²$2.4. In 1900 we note M²$5.9 of placer-gold and M²$2.2 from the lodes. Of this great placer production M²$4.7 is credited to Nome.

Future Tendency.—The lodes along the southeastern coast will probably hold their own or increase for many years, as the

most important ones contain great low-grade ore-bodies, the assay value of the ores on Douglas Island being often less than \$2.50 per ton. Many veins with high-grade ore are likewise found in this coast-belt which also promise well for the future.

If no further placer discoveries of importance are made, the output of placer-gold of Alaska will doubtless gradually diminish. But in a country like Alaska, where prospecting operations are difficult and the pay-streaks usually hidden by layers of barren material, it is not impossible that rich districts like Cape Nome, or even like the Klondike, may be discovered at any time during the next few years.

Arizona.

Statistics.—The total gold-product of Arizona is not known with accuracy, but will scarcely exceed M^2\$42.0. During the period 1877–1900, inclusive, the Territory produced M^2\$33.6. From a small beginning in the early seventies the gold production gradually increased, and reached M^2\$1.0 in 1881. At this figure it remained to 1892, from which time a decided and almost uninterrupted increase is noted; the two-million-dollar mark was reached in 1895, and M^2\$4.2 in 1900. The principal production is divided among the following counties: Cochise, Yavapai, Pima, Pinal and Yuma. Yavapai county ordinarily leads in production.

Geological Features.—The gold-deposits of Arizona are mainly confined to the southwestern half of the Territory, the north-eastern part being chiefly occupied by the level strata of the plateau region. This mineral-bearing southwestern half of the Territory is characterized by numerous short desert-ranges, having a general NW. strike and being separated by broad, sandy valleys. The ranges consist of pre-Cambrian granites and schists, or of an overlying series of Paleozoic quartzites and limestones, with frequent intrusive masses of Cretaceous or early Tertiary porphyries. Large areas are flooded by Tertiary lavas. On the whole, very little accurate information is available as to the geological age and the classification of the gold-deposits. There are certainly some veins which break through Tertiary lavas, principally rhyolite, and which must be considered as belonging to the propylitic post-Miocene group. Among these is the Commonwealth mine, in Cochise county, the vein of which is contained in rhyolite, and which carries gold and

silver in quartzose gangue. A third of the value is in gold and the remaining part in silver. This remarkable deposit has contributed largely to the gold production of Arizona during the last six or seven years.

Another important producer is the Mammoth mine, with adjoining properties in Pinal county, which is associated with a rhyolite dike in granite. This deposit is greatly altered by oxidation, and contained originally, in all probability, smelting rather than milling ore. Central and southwestern Arizona contain many veins which break through schists apparently pre-Cambrian. Among these are the veins of the Prescott district, the best known representative of which is the Congress mine, in Yavapai county, a quartz-bearing fissure-vein containing auriferous pyrite and breaking through granitic rocks; further, the Gold King and the Fortuna mines, in Yuma county, both of which appear to be free-milling fissure-veins contained in older rocks. The age of none of the latter deposits is definitely known. It is known, however, that in the southeastern part of Arizona there are, first, extensive flows of basalt and rhyolite belonging, unquestionably, to the Tertiary period; second, widespread intrusions of porphyry which are distinctly older than these lavas, and which have suffered a great deal of erosion before the eruption of the lavas. These porphyries break through rocks of Cretaceous age, and the mineral deposits associated with them are in all probability Cretaceous, or at latest Eocene. From these observations it is clear that the gold-deposits of Arizona comprise at least two groups: one of the Tertiary—probably post-Miocene—age, and the other of Cretaceous or earlier Tertiary age.

A certain smaller part of the gold production is further derived from smelting-ores, principally the copper-ores of United Verde and Bisbee, and lead-ores from various points. The age of these is not known, but they are believed to be pre-Miocene. It is not quite clear from statistics whether the gold contained in the copper is credited to the Territory or not.

Distribution.—It is impossible to accurately subdivide the present and past output of the Territory. Of the M^2\$4.2 produced in 1900, it is probably not too much to credit M^2\$2.0 to the post-Miocene propylitic veins, dividing the rest among the copper-ores, the small amount of lead-smelting ores and the free-milling ores.

The placers in Arizona, as may be expected from the arid climate, are not worked extensively. If water were available, the production could be materially increased. Statistics from 1897 to 1900 give from M^2\$0.01 to M^2\$0.02 as the output of placer-gold per annum.

Future Tendency.—Induced by the successful ventures of the past few years, prospecting has been carried on in Arizona in a very active manner, and with encouraging results. In spite of the great increase during the past few years, it is perhaps not unlikely that a still further increase in the output will take place. To one familiar with the Territory the possibilities seem great, and it is at least to be expected that the present output will be maintained for many years.

California.

Statistics.—The total gold production of California since 1849 is M^2\$1380.0. The early production is, of course, only approximately known; more accurate figures are available since 1877, and the output from 1877 to 1900, inclusive, is M^2\$351.1. From the time of discovery the production rapidly rose to its maximum, M^2\$65.0 in 1853; from this time it gradually and steadily sank to M^2\$18.0 in 1873. From the latter date to 1893 it fluctuated, but sank on the whole gradually to M^2\$12.0 in 1893, which was the lowest point reached. The rise from 1893 to 1900 has been slow and not quite regular. In 1900 M^2\$15.8 was produced, and in 1901 this was still further increased to nearly M^2\$17.0.

Geological Features.—The principal gold-belt extends throughout the State, being, however, chiefly confined to the slope, which drains directly to the Pacific Ocean. It begins in Lower California, more than 100 miles south of the boundary line, and continues through the southern counties up to the Sierra Nevada, where it reaches its maximum development, swinging from there in a NNW. direction to the counties of Trinity, Siskiyou and Shasta, in the extreme northern part of the State. In Lower California and in San Diego county the veins occur in small masses of altered sediments enclosed in granodiorite. In the main gold-belt of the central counties there is the complicated vein-system of the so-called Mother Lode, breaking through slates and altered volcanic rocks of Carboniferous and Jurassic age, and often at a considerable distance from the

granitic rocks. In Tuolumne and Calaveras counties, and especially at Nevada City and Grass Valley (Nevada county), the veins occur in and about smaller intrusive masses of granodiorite and allied rocks. Though less well known, the conditions of occurrence in the northern counties seem to be of a similar nature. This remarkable gold-belt, the most important one on the North American continent, is characterized by rich and extensive placers; the primary quartz-veins from which the placers were derived contain free gold down to the greatest depths attained, and, besides, a certain amount of auriferous sulphides. The ores contain very little silver. The age of this belt of normal gold-quartz veins is Cretaceous, and its period of formation falls between the very latest Jurassic and the latter part of the Cretaceous period.

Practically all of the primary deposits are of this age; very few, if any, veins of this belt belong to the Tertiary period. The Cretaceous gold-quartz veins of California seem to stand in causal connection with the large areas of granitic and dioritic intrusive rocks of Mesozoic age, but occur mostly in the sedimentary series just outside the main body of granites and granodiorites.

A second gold-belt of considerable importance appears in the eastern part of California within the drainage of the Great Basin, or Colorado river. This is distinctly of Tertiary age, the veins occurring in many places in andesites and rhyolites, and allied rocks. The ores are characterized by containing both silver and gold, and seem to belong to that remarkable class of deposits formed near the surface in volcanic rocks, and in comparatively recent times, to which the name of "propylitic" veins has usually been given. It is not certain, however, that all the ore-deposits of this belt, which begins in Alpine county and continues through Mono, Inyo and San Bernardino counties, really belong to this period; some of them may well be of Cretaceous age.

Distribution.—By far the largest part of the product of California is derived from the Cretaceous gold-belt. The gold-silver veins are the principal Tertiary deposits of Bodie, Mono county. The production of the Bodie mines from 1877 to 1888 is estimated to be about $M^2\$12.0$. Mono county during the same period produced $M^2\$26.0$. The output of Inyo and San Ber-

nardino is not large, and we may, as an approximation, say that the total output of the Tertiary belt from 1877 to 1900 is not more than M^2\$30.0 at the most. This leaves, approximately, M^2\$320.0 as the output of the Cretaceous belt during the same period. In 1900 Mono, Inyo and San Bernardino counties produced an aggregate of M^2\$1.5, out of a total production for the State of M^2\$15.8, and, as stated above, a part of this amount (1.5) is probably derived from deposits of greater age than the Tertiary period.

Regarding the proportion of gold derived from placers to that from quartz-mines, it is apparent that by far the larger part of California's total output is placer-gold. Though accurate statistics are not available, we may assume that less than 6 per cent. of the total has been extracted from quartz-mines. Since 1897 statistics are available which show that the amount of placer-gold produced gradually declined from M^2\$4.3 in 1897 to M^2\$3.2 in 1900. It forms thus from 30 to 20 per cent. of the total output during these years.

Future Tendency.—In all probability the output of placer-gold in California will steadily decrease. Even the introduction of dredging as a profitable and important part of placer-mining has not been able to stay the decline. If the hydraulic mines could be worked, which is not likely, two or three M^2\$ would be added to the product annually for some time to come; but, nevertheless, eventually the decrease would continue.

The old mining counties of Nevada, Placer, Amador, Calaveras and Tuolumne still hold their own; the increase in the production is due not so much to the old mines as to unexpected discoveries of other districts in Kern, Shasta, Siskiyou and Trinity counties. These, together, are responsible for M^2\$4, and their production will probably continue, and even increase, for many years. The copper-mines of Shasta county have contributed a fair sum during the last few years to the gold production. On the whole, California may be expected to hold its own for many years in the production of the yellow metal; but a great increase over the production of 1901 is not very likely.

Colorado.

Statistics.—Accurate data concerning the output of gold in Colorado are only available since 1877. From 1877 to 1900,

inclusive, the production amounted to $\mathrm{M}^2\$204.3$, increasing rapidly during late years. The total production since the first discoveries in 1858 is, on the slender basis of available data, estimated to be $\mathrm{M}^2\$251.1$. This figure will doubtless be pronounced too low by many, but it must be remembered that Colorado did not, like California, Idaho, Oregon and Montana, possess many and rich placer-mines, and that, consequently, the early output was not as heavy. The early placer-mining from 1858 to 1867, inclusive, is estimated to have yielded from $\mathrm{M}^2\$25.0$ to $\mathrm{M}^2\$30$.

From 1877 to 1890 the production ranged from $\mathrm{M}^2\$3.0$ to $\mathrm{M}^2\$4.0$ per annum, chiefly from Gilpin, Clear Creek and Boulder counties; partly, also, from the San Juan region. From 1890 a decided increase began, the output reaching $\mathrm{M}^2\$9.5$ in 1894, $\mathrm{M}^2\$19.1$ in 1897, and finally $\mathrm{M}^2\$28.8$ in 1900. This extraordinary growth was primarily due to the Cripple Creek district, discovered in 1892, but also to the San Juan region, in the southwestern part of the State.

In 1900 Cripple Creek produced $\mathrm{M}^2\$18.1$, the San Juan region (including the counties of Ouray, San Juan and San Miguel) $\mathrm{M}^2\$4.0$, the Leadville district $\mathrm{M}^2\$2.7$, and Gilpin, Clear Creek and Boulder counties $\mathrm{M}^2\$2.7$.

Geological Features.—For many years Colorado has been standing at the head of silver-producing States, and in 1899 it passed California in production of gold. It now easily leads all the other States with an output of nearly $\mathrm{M}^2\$30.0$. Emmons* states justly that "the geological structure of its numerous high mountain ranges, showing the results of repeated and powerful orographic movements, accompanied by plentiful outbursts of eruptive rocks, indicates conditions peculiarly favorable to the concentration of metallic minerals into ore-deposits. . . . It is in the older crystalline and eruptive rocks . . . that gold-bearing ores are mainly found." Placers first attracted the miners—in 1859 and 1860—to what was then a comparatively unknown region; but the greater part of the gold output has not been derived from these, as in California, Oregon, Idaho and Montana. Most of the gold has been derived from vein-mining, at first to a great extent as a by-product of treatment of silver-

* *Mineral Resources of the U. S.*, Calendar year, 1892, *U. S. Geol. Surv.*, Washington, 1893, pp. 63, 64.

ores, but during later years more and more pronouncedly from ores containing gold predominantly. Emmons further says: "The mountain masses of Colorado are divided . . . into two north and south uplifts—the Colorado or Front Range and . . . the Sawatch uplift, with a third uplift, the San Juan group, at the south. The two first-named uplifts consist of a nucleus of . . . ancient crystalline rocks surrounded by a . . . fringe of upturned Paleozoic and Mesozoic sediments, the whole cut through by dikes and intrusive sheets of eruptive rocks. . . . Here, the . . . silver-bearing ores are mostly found in the Paleozoic limestones, while the crystalline rocks afford both gold and silver." The San Juan group is characterized by heavy flows of andesite and other tertiary eruptives, and below them and in them erosion has uncovered intrusive bodies of dioritic and porphyritic rocks of same age. These igneous flows and stocks rest on heavy Mesozoic sediments, and contain rich veins of gold and silver. Gold-deposits of Archean age are not known in Colorado. As far as the age has been determined, the deposits are divided into a smaller Mesozoic and a much greater Tertiary and probably chiefly post-Miocene group.

The Leadville deposits in the Mosquito range on the east side of the Sawatch represent the Mesozoic division.

In 1860, and subsequent years, placers were worked near Leadville, and M^2\$10.0 or more is reported to have been extracted. The primary deposits worked since 1877 consist chiefly of silver ores in limestone along contacts of intrusive sheets of porphyry. During later years, important low-grade gold-deposits have been discovered in the same vicinity. Up to 1893 these smelting gold-ores had yielded M^2\$4.5; since that time the gold production has greatly increased, reaching M^2\$1.5 in 1895, M^2\$1.9 in 1897, and M^2\$2.7 in 1900, giving a total since discovery of probably M^2\$16.0. Emmons regards the Leadville deposits as of Cretaceous or even possibly of Jurassic age. (*U. S. Geol. Survey, Geolog. Atlas of the U. S.*, Folio 48, Ten-Mile District.)

In no State are the Tertiary propylitic deposits developed on such a scale as in Colorado. Of deposits belonging to this age, those of Gilpin, Clear Creek and Boulder counties form a well-defined group. Earliest of discovery, they have been worked for forty years. The gold production has been remark-

ably steady, being from M²$1.0 to M²$3.0 per annum. The whole district has produced an approximate amount of M²$48.0 since 1860. The ores contain both gold and silver, though at the present time the value of the gold exceeds considerably that of the silver. Boulder county produces telluride ores, three-fourths of the value of which is in gold. Clear Creek county produces complex smelting-ores, with much silver. Gilpin county, which is the greatest producer of the three, contains mostly pyritic gold-ores with free gold, which are treated by amalgamation and concentration. The gold output during the last four years was as follows: In 1897, M²$3.5; in 1898, M²$3.0; in 1899, M²$3.1; and in 1900, M²$2.7. The veins occur in Archean gneisses and similar rocks, and their formation is later than the accompanying andesite dikes, according to a recent note by H. Foster Bain. Consequently they are of Tertiary age. The character of the ores and the absence of large placers lend support to this view.

The second and most important center of gold production is at Cripple Creek. The extremely rich network of narrow veins occurs in Archean granite or in overlying andesite or phonolite. They contain gold-ores almost exclusively, which, however, are not free milling, but contain much telluride, and are usually treated by smelting, chlorination, or the cyanide process. Their age is Tertiary, but the precise epoch cannot be ascertained. The volcanic eruptions in Colorado began during the earliest part of the Tertiary and continued until a comparatively recent date. The output of Cripple Creek dates from 1892, when M²$0.6 was recorded. The production rose rapidly to M²$6.9 in 1895, M²$10.1 in 1897, and M²$18.1 in 1900, —the greatest gold output ever recorded in the United States from a vein-mining district. (The Comstock in 1877 yielded M²$14.5 in gold and M²$21.8 in silver.) In 1901 the production receded to M²$17.3. The total production of Cripple Creek from 1892 to 1900, inclusive, is M²$77.3.

The San Juan region in the southwestern part of the State embraces the counties of San Juan, San Miguel and Ouray, and several others of minor importance. These districts are of comparatively recent discovery, only having been worked to small extent previously to 1880. The region has produced a large amount of silver; but until about 1889 the gold output

was below M²$1.0, and during the decade 1880–1890 only averaged about M²$0.3. But from 1890 the increase was more rapid, and the production reached M²$1.0 in 1892, M²$1.4 in 1894, M²$2.0 in 1896, M²$3.5 in 1898, and M²$4.0 in 1900. The total gold product of the San Juan region is probably about M²$24.0. The veins contain some ores with silver alone, others with gold and silver, and, more rarely, some with gold alone. Most of the great veins cut the thick andesitic and rhyolitic flows, and the ore-shoots thus far exploited comprise the upper part of veins, formed relatively near the surface. Below the volcanic rock lie Eocene and Mesozoic sediments, but the workings have not penetrated far into these.

In the La Plata district, adjoining the San Juan on the south, the erosion has been greater than at other places, and has exposed large bodies of intrusives, such as diorites and monzonites, which are younger than the surface lavas in which they are contained. The diorites and monzonites are cut by silver- and gold-bearing veins, but the production of gold from them is thus far not considerable. We have here mineral veins exposed which were formed at a level considerably lower, relatively to the original surface at the time of vein-formation, than those of Silverton and Telluride in the central part of the San Juan region, and the comparison of the two might reveal interesting points. The districts have been described by Purington and Ransome. The San Juan quartzose gold-ores are usually treated by amalgamation and subsequent concentration. The age of the veins of San Juan is probably late Tertiary, almost certainly post-Miocene. Many other districts in Colorado produce gold in smaller quantities, but the four districts described are the principal ones.

Distribution.—According to the above description, by far the largest portion of the output is to be credited to the veins of Tertiary—largely post-Miocene—age. Of the total of M²$251.0 (?), probably not more than M²$34 belongs to the Mesozoic deposits. Of the output in 1900, amounting to M²$28.8, not more than M²$3.0 is likely to be from Mesozoic deposits.

The placers of Colorado have never been of great importance. In 1880 the placer-gold was only 3.77 per cent. of the gold output for that year. During the last years the placer-pro-

duction has gradually increased, owing to the introduction of dredging and other improved methods. In 1897 M²$0.2 was derived from placers out of a total gold production of M²$19.1. In 1900 M²$0.7, out of a total of M²$28.8.

Future Tendency.—The production of the Gilpin region will probably continue at about the present figures for a long period. Similar results may be expected at Leadville, although, perhaps, a continued increase over the present figures is not to be expected. The San Juan region promises well from the strength of the veins, and from the fact that only their upper parts have been worked, but a very great increase is perhaps not to be anticipated.

The Cripple Creek district has increased its output at a phenomenal rate, and unquestionably a production of great importance will be maintained for many years. But whether, with increasing depth and accompanying expense of working, a still further increase will take place seems doubtful.

Idaho.

Statistics.—Since the discovery of gold, the State of Idaho is believed to have produced M²$112.8. From 1877 to 1900, inclusive, the output of gold was M²$42.8. The early statistics are, of course, very uncertain, but it is believed that the maximum, M²$8.0, was reached in 1866, three years after discovery of the placers. From this figure a gradual decrease to M²$1.1 in 1878 took place. From this minimum the gold-production increased to M²$2.4 in 1887, since which time it has fluctuated between M²$1.7 and 2.3. During the last four years it has been about M²$1.7, except in 1899, when it reached M²$1.9.

Geological Features.—The southern part of Idaho may be considered as belonging to the Great Basin. It is characterized by isolated desert ranges of folded sediments, intrusive granites and overlying Tertiary lavas, which show extensive mineralization only in the southern part of Owyhee county. North of the great Snake River Valley extends the great central mountain mass, with an enormous amount of intrusive, probably late Mesozoic, granite, surrounded along the boundaries of the State by sediments ranging from Archean to Mesozoic in age. The gold-deposits of Idaho are divided into two distinct classes:

(1) A pre-Miocene series, probably of Cretaceous age, and most likely formed at about the same time as the California and Oregon gold-quartz veins. These occur chiefly in the great granite area of the State, which is known to be post-Carboniferous and pre-Miocene, and which appears to have been intruded at approximately the same time as the great granite batholiths of California. These deposits are characterized in Idaho, as in Oregon and California, by remarkably rich placers and by veins of less importance. Examples of these districts are the great placers of the Idaho Basin, Florence, Pierce, Warren, Elk City, etc. With all of these, quartz-veins are associated, which, however, in many places, have proved disappointing in yield. Though most of them are normal quartz-veins, carrying free gold in depth, we note a distinct change from California, inasmuch as more silver is ordinarily present, and many veins contain large amounts of sulphides with small amounts of free gold. Going northeast from California to Oregon, Idaho and Montana, this change in the earlier quartz-veins becomes very marked.

(2) To the post-Miocene series belong the Owyhee veins south of Snake river, occurring in basalt and rhyolite. To the same division belong, probably, also, the celebrated Custer mine; possibly, also, the Rocky Bar and Atlanta veins, the age of which cannot, however, be proved; and, finally, according to reports, the recent Thunder Mountain discoveries, which appear to occur in Tertiary rhyolite. This post-Miocene belt of ore-deposits, reaching up from near the Nevada line towards the center of the State, contains veins which show the usual propylitic type, and are characterized by containing both silver and gold.

Distribution.—Though the output of placer-gold has steadily decreased since early days, it has remained remarkably constant during the last few years. Out of an annual product varying from M^2\$1.7 to M^2\$1.9, the placer-gold consists of from M^2\$0.6 to M^2\$0.7,—that is, not far from one-half. This is an unusually large percentage, and is not exceeded by any member of the Union excepting Alaska. Of the total product of M^2\$112.8, it is not probable that more than M^2\$20 is derived from the vein-deposits. Of this amount, at least M^2\$12.0 comes from Owyhee county, and the rest from the celebrated veins of Gold Hill,

Atlanta, Rocky Bar, and Custer. Of the total production, we may assume that M²$90.0 is derived from the Cretaceous deposits, while the remainder, M²$22.8 is derived from veins of post-Miocene age. Out of the total for 1900, M²$1.7, M²$0.9 is probably derived from post-Miocene and M²$0.08 from pre-Miocene gold-deposits.

It is thus seen that, although the post-Miocene deposits contribute but a small amount to the total output of the State, their importance in the present annual production is very great, inasmuch as they form over one-half of this amount.

Future Tendency.—Regarding the placer-mines, it is probable that their output will later gradually decline, but for many reasons it is believed that this decline will be unusually slow. Regarding the lode-mines, it is difficult to say what the developments of the next few years will show. The past has shown a rather spasmodic production; veins have been discovered containing great bonanzas which were rapidly exhausted, and periods of inactivity followed. As a whole, the Cretaceous gold-quartz veins have been a disappointment, while the post-Miocene propylitic veins have produced great bonanzas, and it is not beyond the bounds of possibility that more may yet be found.

Montana.

Statistics.—The total product of gold in Montana is very difficult to ascertain. Mining began upon the discoveries of rich placers in 1862, and this placer-gold is the most uncertain factor. As much as M²$260.0 has been claimed (see Mint report for 1897), but this seems doubtful. According to Ross E. Browne, the output from 1862 to 1867, inclusive, was M²$65.0. From 1877 to 1900, inclusive, the output is M²$83.6. A total since discovery of M²$203.5 is probably nearer to the mark than M²$260.0.

During the first years the placers of Madison and Beaverhead counties gave the largest output; later, those of Prickly Pear Gulch and Confederate Gulch; still later, smelting-ores and silver-gold milling-ores produced most of the gold. For many years past the counties of Lewis and Clark and Jefferson have been leading in the production of gold. But a great number of other counties participate, among them Deer Lodge, Silver Bow, Granite, Meagher, Fergus, Madison and Beaverhead.

Since the days of the great placers, Montana's gold production has always been characterized by relative constancy and slow changes. After the discovery of gold, in 1862, the maximum was reached in 1866 with M^2\$16.0, but it soon declined. In 1875 the production was only M^2\$2.7; in 1882, M^2\$2.5. These totals were gradually raised to M^2\$6.0 in 1887, the increase being chiefly due to the smelting of gold-bearing silver-ores and to some great gold-silver-quartz veins. The production of silver bullion began about 1872. From this point a gradual decrease carried the production down to M^2\$3.6 in 1894. Since 1897, the production has varied between M^2\$4.4 and M^2\$5.1, and was M^2\$4.7 in 1900. A considerable part of this amount is derived from the copper-smelting-ores of Silver Bow county.

Geological Features.—The Rocky Mountains do not present as clearly defined orographic units in Montana as in Colorado. There are several minor front ranges, usually consisting of upturned Paleozoic and Mesozoic sediments, with cores of Archean rocks and of post-Cretaceous porphyries. The western part of Montana may be regarded as the extension of the great Idaho uplift, modified by faults, and is characterized by the occurrence of many great intrusive masses of granitic and dioritic rocks. These intrusives are apparently of still later age than those of California, Oregon and Idaho. The Butte, Boulder and Helena granites are believed by Mr. Weed to be either of very latest Cretaceous or earliest Tertiary age, and to have been laid bare by an erosion of great magnitude. Extensive areas of Tertiary surface-lavas occur only in the part adjacent to the Yellowstone National Park. The eruptions of igneous rocks began in Montana at the close of the Cretaceous, and continued vigorously through the earlier epochs of the Tertiary; but the outbursts of the later epochs were of less importance.

The gold-deposits show, as a whole, a decided analogy with those of the Pacific coast, but there are marked modifications. Montana stands second only to California in the great placers which were worked in the early sixties. Much of the gold was obtained from the gravel-deposits of Bannack and of Alder Gulch, at Virginia, both in southern Montana; the latter are currently reported to have produced M^2\$30.0. After the placers

of Alder Gulch, those near Helena, on the west of the Missouri, and at Confederate Gulch, in the Big Belt Mountains, were discovered, and yielded their millions. These placers undoubtedly indicate the presence of gold-quartz veins closely akin to the California type, but at most of the places mentioned the primary deposits have proved disappointing, and have ordinarily yielded only moderate sums. The veins chiefly occur in Archean terranes or in late intrusive granite. There are at present but few normal gold-quartz mines of the California type worked in Montana. More common is a type of quartz-vein which contains both gold and silver, like the Drum Lummon at Marysville, which has produced several million dollars. Still another prominent type is the one containing mixed smelting-ores without much free gold, but usually with much silver. A considerable amount of the Montana gold is, in fact, obtained as a by-product from the smelting of silver-lead ores, although this class of ore is not now mined as extensively as it was a decade ago.

Another and very important part of the gold output is derived from veins in granite, chiefly near Butte, which carry copper-ores containing a little gold, together with much more silver. The great majority of all these veins, comprising many kinds of ores, occur in the intrusive granites or in the surrounding sediments which have been affected by contact metamorphism. To this group belong the Granite Mountain mine, the Drum Lummon, the Elkhorn, the mines at Uniston, and the Whitlatch-Union lode near Helena. According to Mr. W. H. Weed, they were probably formed at about the same time, shortly after the great granitic intrusions, and belong to the very latest Cretaceous or the earliest Tertiary. As to the time of formation, they may be regarded as a connecting-link between the distinctly Mesozoic gold-quartz veins of the Sierra Nevada, and probably, also, of Idaho and Oregon, on the one hand, and the propylitic, distinctly post-Miocene veins of Colorado on the other. Most of them manifestly represent the deeper portion of veins, the upper parts of which have been carried away by erosion, very likely to the extent of several thousand feet.

In the Judith mountains, and other isolated groups, interesting gold-bearing replacement deposits in limestone and porphyry accompany the intrusion of what are probably Eocene

phonolitic magmas. In general character these appear rather closely connected with the propylitic veins. The post-Miocene volcanic rocks show a mineralization at many places, but contain but few deposits of great importance.

Distribution.—It seems thus that practically the whole gold-production of Montana should be credited to the late Mesozoic or early Tertiary group, their formation being due to the intrusion of great granitic batholiths.

Many distinctions may be made as to the character of ore. The whole of the early production up to 1868 was placer-gold and is estimated at M^2\$64.5. In 1880 two-thirds of the production of M^2\$2.4 was placer-gold. This ratio diminished in 1884 to about two-fifths, or M^2\$0.96 in M^2\$2.4. Since the latter date the output of placer-gold has been remarkably constant, showing very slight decrease. In 1900, it was M^2\$0.6 in a total of M^2\$4.7. This is partly due to the recent introduction of dredging in the southern gold-fields, chiefly at Bannack.

The output from gold-quartz and gold-silver-quartz ores (mill-bullion and cyanides) varied from M^2\$1.4 in 1897 to M^2\$2.3 in 1900. The lead and mixed smelting-ores yielded M^2\$1.2 in 1897 (total output M^2\$4.4), and M^2\$0.7 in 1900 (total output M^2\$4.7). As these ores carry chiefly silver, the decrease is probably due to the falling price of that metal.

The gold from Butte copper-ores is a very important item. Since 1882 these mines have produced about M^2\$331.0 in copper, M^2\$86.0 in silver, and M^2\$14.5 in gold. Some of the gold and silver is, however, derived from the dry ores of the Butte silver-mines. The amount of gold from copper-ores in Montana amounted to from M^2\$1.1 to M^2\$1.2 per annum during the four years 1897–1900.

Future Tendency.—The output of placer-gold will probably remain at about its present level for several years. Regarding mill-ores, it is true that some great ore-shoots seem to have been exhausted, but new discoveries and low-grade deposits will probably continue to keep this factor at its present value for a long time. A falling price for copper and silver and a possible diminution of the copper-production would tend to diminish the gold from miscellaneous smelting-ores and from copper-ores. Owing to the rarity of propylitic Tertiary veins, great bonanzas of this class can hardly be expected. On the

whole, it is expected that the production for the next few years will continue steady and at about the same level.

Nevada.

Statistics.—The total product of Nevada in gold since the discovery of the mining-districts, about 1860, is supposed to be in the vicinity of M^2\$250.0, although this estimate is very uncertain. Of this amount, about M^2\$148.0 has been contributed by the great Comstock lode since its discovery in 1859. The known output of the State from 1877 to 1900, inclusive, is M^2\$99.7. From a maximum production of M^2\$14.5 gold in 1877, the output steadily declined to less than M^2\$1.0 in 1893. From this time an increase has taken place, and the production for the four years from 1897 to 1900, inclusive, was, respectively, M^2\$3.0, M^2\$3.0, M^2\$2.2 and M^2\$2.0. The larger part of the product during these last years was derived from the De Lamar mine in Lincoln county, though the Comstock, Eureka and other districts have added their quota.

Geological Features.—Nevada is characterized by a great number of minor arid ranges, with a general N.–S. trend, and separated by desert valleys. The older rocks are largely folded Paleozoic and Mesozoic sediments, cut by many intrusions of porphyry and flooded by Tertiary rhyolites, andesites and basalts. The origin of the ranges is probably largely due to faulting. Few large intrusive batholiths like those of California, Idaho and Oregon appear to be present.

Mineral deposits of great diversity and often unknown age are scattered over the whole State excepting possibly the northwestern corner, which is covered by large and barren lava flows. It is not to be doubted that pre-Miocene veins and deposits occur in the State. Gold-quartz mines of the California type are very uncommon, but seem to have their nearest representative in the Silver Peak mines in Esmeralda county, which, according to Mr. Turner, appear to antedate the great volcanic eruptions in that vicinity, and which chiefly occur in Paleozoic rocks.

Another class of deposits which is very common, and which principally carries gold as a by-product, is that of argentiferous lead-ores and other smelting-ores occurring in limestone near eruptive bodies. The best-known representative of this

group is the Eureka mine, the ores of which carry one-third of their value in gold, and which have contributed about M²$2.0 to the total production. The ore-bodies at Eureka are, according to Mr. J. S. Curtis, of Tertiary age, being connected with a rhyolitic eruption; but it is possible that there are many other deposits of smelting-ores which are older, and probably of Cretaceous age.

There is, finally, the important division of the propylitic veins, which were formed, in most cases, since the Miocene period. Among their characteristics is a peculiar alteration of the adjoining rock and a tendency to contain both gold and silver, the value of the latter being usually greater than that of the former. The most prominent representative of this propylitic group is the Comstock lode, which is credited with a total production of M²$368.0. Of this total, M²$148.0 is believed to be gold. The Comstock lode breaks through andesite of Tertiary age, and the ores, like all of those belonging to the propylitic group, are dry—that is, they contain rich silver- and gold-minerals in quartzose gangue without sufficient lead or copper to render them good smelting-ores.

Another important gold- and silver-producing district is that of Tuscarora, in Elko county, well up toward the Idaho line. Tuscarora affords a connecting-link between the Tertiary veins of Nevada and those of Idaho.

A comparatively late discovery is the De Lamar mine, in southern Nevada, Lincoln county, which for the last few years has contributed from one to two million dollars to the production of the State. This, also, contains both gold and silver, according to the description of Mr. Emmons, and it seems probable that, although the vein breaks through quartzites, it belongs to the post-Miocene group.

Distribution.—From the data given above it is clear that by far the largest part of the gold-production of Nevada is to be credited to the Tertiary propylitic veins. Older deposits may have contributed a few millions, but in the absence of more detailed knowledge regarding them it is not safe to give a more defined estimate. The output of placer-gold in Nevada is extremely small, varying from $20,000 to $100,000 per annum. This is largely due to the scarcity of water, but it has also been remarked that the propylitic veins are very seldom

accompanied by such great placers as are found below the veins of the normal gold-quartz type.

Future Tendency.—Like most regions which chiefly contain propylitic veins, the history of mining in Nevada has been marked by great bonanzas found in different places and at different times. The exhaustion of the bonanzas has been followed by periods of greatly reduced production. Although it is not to be expected that another Comstock will be found, yet there is a fair probability that rich ore-bodies will continue to be discovered from time to time. Tonopah is a case in point. The ores at this place appear to be of the normal, propylitic variety, containing both gold and silver, and are reported to occur in andesite. The abundance of prospects of gold-bearing ores in nearly every part of the State leads to the belief that eventually many good mines will be found and developed, especially if the country is made more accessible by the extension of the lines of communication.

New Mexico.

Statistics.—Placer-mining has been carried on in New Mexico by the Spaniards and Mexicans since their occupation of the country, in the latter part of the sixteenth century. The amounts extracted by these old miners cannot be estimated, but they were probably not very large. From 1877 to 1900, inclusive, the Territory of New Mexico has produced M^2\$13.3 gold. The total production since 1860 is in all probability about M^2\$17.6. In 1877 the production was M^2\$0.3, which gradually increased to M^2\$1.0 in 1889. It gradually sank again to M^2\$0.4 in 1897, but increased from that period, so that the output in 1900 amounted to M^2\$0.8. The principal producing county is that of Grant, containing the deposits of Pinos Altos, but many other counties contain producing mines.

Geological Features.—Our knowledge of the geology of New Mexico is very fragmentary,—more so than that of any other State or Territory. The numerous desert-ranges which characterize the State usually show a folded and faulted Paleozoic series, flooded by enormous masses of Tertiary lavas. In a recent paper, Prof. Herrick states that gold occurs mostly in igneous rocks, and chiefly in andesites, trachytes and rhyolites, the latter being the youngest. The basalts are barren. The

andesite is stated to be the most productive formation. From the description mentioned, it appears, however, that the igneous rocks mentioned are only partly lava-flows, and that a number of them clearly belong to the class of intrusive porphyries. There is, no doubt, a great similarity between New Mexico and Colorado, and it is to be expected that similar classes of deposits will be found. Most probably, then, the gold-veins should be divided into a later post-Miocene propylitic series and an older division, connected with intrusive porphyries. The age of the latter can only be conjectured; they may be Cretaceous; but, on the other hand, a short distance north of New Mexico, in southern Colorado, the erosion has been so intense as to expose intrusive diorites of late Tertiary age in the same districts with late Tertiary lava-flows. Beyond the point, then, that a certain number of the gold-deposits of New Mexico are post-Miocene, nothing further can be said with certainty. The gold-veins of Pinos Altos, in Grant county, occur in granitic rocks, and are connected with dikes. In depth the sulphides predominate, and a little free gold is present. The production rose to M^2\$0.4 in 1900.

In the Shakespeare district, south of Lordsburg, in the same county, large quartz-veins in diorite contain auriferous sulphides. Another well-known gold-mining district is that of the Mogollon Mountains, in Socorro county, which is said to contain free-milling ore between walls of porphyry or andesite. Sierra county contains low-grade ore-deposits at Hillsboro. Bernalillo county affords, at Cochiti, large, low-grade ore-bodies in igneous rocks. In a recent description of the San Pedro district, in Santa Fe county, Messrs. Yung and McCaffery* show the existence of several cores of syenite-porphyry intrusive in old sedimentary rocks. Gold-quartz deposits as stringer-leads and fissure-veins cluster characteristically about the contacts. This is the most important old placer-district in New Mexico, and also contains the celebrated Ortiz vein, said to have been worked by Indians previously to the Spanish occupation.

Distribution.—In the absence of further knowledge, it does not seem possible to divide the product among the different classes of deposits. It might be said that probably at least one-half of the output is dervied from post-Miocene, propylitic veins.

* "The Ore-Deposits of the San Pedro District, New Mexico," present volume, p. 350.

The output of placer-gold is now comparatively insignificant, and amounts to from $20,000 to $70,000 a year. From 1865 to 1875 the placers were worked with considerable success, and probably yielded several millions of dollars. Small amounts of gold have been produced from copper-ores in the San Pedro Mountains. Silver, possibly containing a little gold, is obtained from a belt of deposits of galena in limestone in the southern central part of the Territory, near Cook's Peak, on the west side of the Rio Grande Valley.

Future Tendency.—A steady increase in production has taken place during the last four or five years, and prospecting operations have been very active. From this, it would seem likely that a still further increase is to be expected during the next few years. The Territory is situated between the great producing regions of Colorado and Old Mexico. Practically every range in New Mexico contains abundant indications of the presence of precious metals, and many of them are certainly of the same post-Miocene, propylitic type which is so prominent throughout the regions to the north and south. Thus, while the production has been small during the past years, the region is not so well prospected but that valuable discoveries may well be made in many of the districts. On the other hand, it is true that the old and important district of Pinos Altos shows a lessened production from that of former years.

Oregon.

Statistics.—The gold-production of Oregon since discovery is believed to be M^2\$54.5. The rich placers were worked out at an early date and the production sank to small amounts, reaching a minimum of M^2\$0.8 in 1888; since that time, owing to the opening of quartz-mines, it has again increased to M^2\$1.5 in 1899 and M^2\$1.7 in 1900.

Geological Features.—The gold-deposits of Oregon are contained partly in the southwestern and partly in the northeastern corner of the State. The former are the direct continuation of the California gold-belt. The mines of northeastern Oregon are similar in character with the California belt, and both districts are evidently of the same age—that is, they belong to the Cretaceous period. In northeastern Oregon there is, however, a slight difference in the characteristics of the

veins, owing to the presence of more silver in places and the occasional occurrence of sulphide-ores containing little or no free gold. The veins are, moreover, clearly connected with the intrusion of late Mesozoic granitic rocks into older Paleozoic and Mesozoic sediments, and were formed shortly after this intrusion.

Post-Miocene deposits have been found in at least one place, the Bohemia mining-district in the Cascade Mountains, where, according to Mr. J. S. Diller, veins of gold and silver occur in andesite. The output from this place is, however, not more than a very small fraction of the annual production.

Distribution.—It is clear that here, again, by far the largest part of the output—in fact, practically the whole—is to be credited to the Cretaceous gold-quartz veins. Regarding the proportion of gold from placers and from lodes, just as in California, the former predominates strongly in the total output. During the last twenty years the placer output has been steadily diminishing and is now from $M^2\$0.4$ to $M^2\$0.3$; the total production for the last few years varies, as stated above, from $M^2\$1.2$ to $M^2\$1.7$.

Future Tendency.—In spite of the introduction of dredgers and an increased activity in placer-mining, the product from these deposits will doubtless continue to diminish, while there is good reason to suppose that within the next few years the output from the quartz-mines will show a fair increase.

South Dakota.

This State contains important gold-deposits in its southwestern section, in the Black Hills. Its total production from 1877 to 1900 is $M^2\$89.4$, all of which is derived from the Black Hills. The total product since the discovery of these mines in 1876 does not much exceed the figure just given. During the last few years the production has risen rapidly. From 1877 to 1889 the production varied from $M^2\$2$ to 3, reaching $M^2\$4.0$ in 1881. Since 1890, it has always exceeded $M^2\$3.0$. In 1896 it had risen to $M^2\$5.0$, and in 1900 it finally reached $M^2\$6.2$.

Geological Features.—The gold-deposits in the Black Hills belong to two distinct classes: first, the great lodes contained in Algonkian and Archean rocks, of which the Homestake is the most prominent example. The deposits are formed by closely-

massed stringers containing, to the greatest depth attained, free gold, and not very rich gold-bearing pyrite. The age of these veins is held to be pre-Cambrian and post-Archean, thus probably Algonkian. Placer-gold is found in the Cambrian conglomerates and sandstones which overlie the outcrops of the old rocks, and was extensively mined during the early days. These views of the age of the Homestake lode are held by W. B. Devereux, Carpenter, Irving and O'Harra, and are generally accepted. Local recurrence of ore-deposition in the old deposits may have taken place during the Tertiary period.

The second division is that of the siliceous ore-belt, recently examined by Mr. J. D. Irving. These bodies are not in distinct veins, but form irregular masses or horizontal shoots at the junction of Cambrian quartzites with the overlying lime-shales. They are connected with vertical fissures, usually barren, which are believed to have formed the duct for the passage of the solutions which caused the deposits. The ore is refractory, and is believed to contain gold in the form of telluride. It ordinarily carries several times more silver than gold by weight, and is said to average from $10 to $15 per ton. This ore is treated by chlorination, pyritic smelting, or cyaniding. While the age of these deposits is not fully known, they are believed to be genetically connected with phonolite dikes of Tertiary age. We have thus, in South Dakota, a series of deposits of very widely differing age, one being pre-Cambrian and the other probably Tertiary.

Distribution.—By far the greatest part of the product of the Black Hills should be credited to the old deposits of the Homestake type. The production has been remarkably steady until the last few years, when the discovery of the siliceous ores caused a considerable increase. During 1900 the free-milling ores produced M^2\$3.8 and the refractory ores M^2\$2.4. Practically, no placer-mining is now carried on.

Future Tendency.—It is stated by those familiar with the mines of the Black Hills that reserves in the Archean belt are very large, assuring a steady production for many years to come. It is not likely that there will be any great increase in the production of gold from the old deposits. Just what the capacity of the refractory ores in the younger belt is, cannot be stated. It is said that explorations have assured an enormous

amount of reserves for the future. We may safely say that the production of the State will probably be maintained at, at least, its present level for many years to come.

Utah.

Statistics.—The production of gold in Utah was not large in the early days of mining; almost the only source of placer-gold was Bingham canyon, from which about $M^2\$1.0$ was obtained in 1867. The larger part of the product has been derived incidentally from the smelting of silver-bearing lead- and copper-ores, which began in 1870. Prior to 1890 the annual production varied from $M^2\$0.1$ to $M^2\$0.5$. From 1890 to 1896 it gradually rose from $M^2\$0.7$ to $M^2\$1.9$. During the last four years the increase has been much more rapid, and in 1900 $M^2\$4.0$ was produced. The total amount from 1877 to 1900, inclusive, is $M^2\$24.1$. The total production is probably $M^2\$27.0$. The most productive counties are Juab and Tooele.

Geological Features.—Utah is divided by the great fault-scarp of the Wasatch range into two provinces. To the east is a plateau country, a region mainly occupied by extensive tablelands. West of this line is the Great Basin, a region of isolated mountain ranges separated by broad desert valleys. The producing mining-districts lie chiefly in the desert-ranges at the foot of the great Wasatch fault. Several mining-districts are, however, situated in the Wasatch Mountains, but these contain mostly silver-lead mines. Among them, the principal producer was the great Ontario-Daly vein, the total output of which, in silver and lead with a little gold, is reported to have reached $M^2\$27$. Utah contains comparatively few deposits in which gold values predominate. Gold-quartz veins of the California type are practically absent, as are also placer-deposits of importance. Post-Miocene veins of the propylitic type, containing gold, appear to be of very rare occurrence, although in the Tintic district and at the great Horn-silver mine at Frisco veins of this class carry silver with an insignificant percentage of gold. The principal type of deposits appears to be represented by veins and irregular masses of ore following contacts of sheets and bodies of porphyry. The ores are usually base, containing much lead or copper, a large amount of silver, and a smaller quantity of gold; their age

is believed to be Cretaceous. In the Tintic district the irregular bodies of base ore contained in the sediments are believed by Tower and Smith to be post-Jurassic and pre-Miocene in age. The production of Tintic, which was less than M²$0.1 in gold in 1888, has risen rapidly, until in 1900 it attained M²$1.6.

Among the gold-deposits proper, the most important producer at present is the Mercur district, in which the gold is extracted by the cyanide process from complex ores in limestone along sheets of porphyry. Silver-deposits are also present at Mercur, but are, according to Mr. Spurr, probably of Cretaceous age, while the gold-ores may be later, and possibly of Tertiary age. The production has rapidly increased during the last few years, and in 1900 the production of Tooele county, in which the Mercur district is situated, amounted to M²$2.0.

Distribution.—Practically the whole gold output of Utah should be credited to pre-Miocene, probably Cretaceous, deposits. Following the Mint reports, we can divide the product for 1900 as follows:

From quartzose ores (cyanide and mill-processes), . M²$2.7.
The production from this source is increasing.

From lead-ores, ... M²$0.4.
This product appears to be steadily decreasing.

From copper-ores, ... M²$0.9.
The gold from this source appears to be rapidly increasing.

Future Tendency.—According to present indications, and the great activity in smelting now shown at Salt Lake City, it is possible that the production of gold from smelting-ores will still further increase. Whether this increase will be permanent is not easy to say. Nothing definite is known as to the permanency of the deposits of the Mercur district. Very recently a gold-mine of great promise has been discovered in the southern part of the State.

Washington.

Statistics.—The total product of Washington is difficult to ascertain, because during earlier years its output was united with that of Oregon in the returns given. The State never possessed very rich placer-mines. The output from 1877 to 1900 is M²$8.9. J. Ross Browne estimates the output previously to 1868 as M²$10.0, which appears too high. Should this estimate be correct, it would bring the total since discovery up to

$M^2\$21.4$. In 1877 Washington produced $M^2\$0.3$, and from 1881 to 1886 the output sank as low as $M^2\$0.1$. In 1896 nearly $M^2\$0.4$ was produced, and the output has increased considerably, until now, in 1900, it is $M^2\$0.7$.

Geological Features.—The great Cascade Range traverses the western part of Washington from north to south. Heavy lava-flows cover a folded series of sediments ranging from Paleozoic to Tertiary. Great masses of granodiorite and diorite of Mesozoic and Tertiary age invade the sediments. Eastern Washington is largely covered by Miocene basalts, but also contains various older rocks in the northeastern part. The two most important sources of gold in Washington are the Monte Cristo mines, in the Cascade Range, and the Republic district, in the eastern part, near the International Boundary line. Besides, there are a number of prospects and partially developed camps on the east side of the Cascade Range. The gold-mines of Monte Cristo are, as shown by Mr. Spurr, clearly of very late Tertiary age, possibly even Pleistocene. On the other hand, the age of the Republic veins is as yet in doubt; but the chalcedonic character of their ore would lead one to infer a comparatively recent age for these veins also.

Distribution.—Placer-gold forms but a small part of the output. From 1896 to 1900 it has varied but little from $M^2\$0.1$ per annum, forming thus from one-third to one-sixth of the total output. The Monte Cristo deposits contain arsenical smelting-ore, while the ores of the Republic Camp are quartzose, and, though difficult to treat, are usually reduced by the cyanide process.

Future Tendency.—The active and successful prospecting that has been going on in Washington for the last few years leads one to expect a fair increase in the product within the next few years. A large part of this should be derived from the Republic district, but it is very probable that new districts of merit will also be discovered on the east side of the Cascade Mountains. Although the matter of age is still in doubt, it would seem as if quartz-veins of the California type are absent or rare, and that the majority of veins are of Tertiary age.

Wyoming.

Statistics.—The production of Wyoming has always been small, and such gold as has been produced has often been re-

ported from adjacent States. For this reason it is very difficult to give the total production, or even arrive at a reliable estimate of current production. The output of gold in 1900 was $M^2\$0.1$; the amount recorded in the Mint Reports from 1868 to 1900 is only $M^2\$0.5$, and the total output cannot at most be much over one million dollars.

Geological Features.—Except in the case of the Medicine Bow and the Park Range, the mountains of Colorado do not continue into Wyoming. The State is characterized by irregular uplifts of Archean rocks flanked by Paleozoic and Mesozoic sediments, and is apparently without large masses of post-Carboniferous intrusions. The uplifts are separated by great areas of Cretaceous and Tertiary sediments. The gold-mining districts are very scattered. A few placers are located near the Colorado line. In the northeasterly corner of the State, where it borders on South Dakota, placer-gold has been found, which is believed to have been derived from Cambrian conglomerates, and which consequently appears to be of pre-Cambrian age and belonging to the same old gold-belt that is so strongly developed in the Black Hills. At Silver Crown, near Cheyenne, irregular and distorted quartz-veins occur in Archean rocks which probably belong to the same gold-belt. Placers and quartz-veins have been found in the Sweetwater mining districts in the central part of the territory. According to the description of Prof. Wilbur Knight, these would also seem to be of pre-Cambrian age. They produced about \$450,000 during 1868–1872. At Great Encampment, copper-ores containing some gold occur in granitic rocks. Of the age of these deposits nothing is known.

Wyoming contains, especially in its northwesterly part, a large area of unprospected country. It has been remarked by many observers that its position between Montana and Colorado, both great gold-producing States, would point to a greater development of the mining industry than the State has thus far shown. Of a total production of $M^2\$1.0$, nearly the whole amount should probably be credited to the pre-Cambrian deposits. At least $M^2\$0.7$ has been derived from placer-mines.

The Appalachian Belt.

Statistics.—Along the Appalachian mountains from Georgia to the Canadian boundary extends a belt of gold-deposits

to which the above name has been given. The gold was discovered and the placers and veins worked long before the great Cordilleran belts were found. The most important deposits are located in Georgia and the Carolinas, but scattered occurrences continue through Tennessee, Virginia and Maryland, and still farther north. The total production from 1799 to 1900 is estimated to be M^2\$47.0 (including a small percentage of silver alloyed with the gold). From 1877 to 1900, inclusive, M^2\$8.0 represents the output. For the last 20 years the total production will average a little over M^2\$0.3; the maximum, M^2\$0.5, occurring in 1882. In 1900 the output was M^2\$0.3.

Geological Features.—The deposits are gold-quartz fissure-veins and associated placers. The latter are at present of small importance, the output during the last few years varying between $50,000 and $70,000. The veins which are profitably worked at several places in Georgia and the Carolinas occur in slates and schists of Archean, Algonkian, and possibly Cambrian age. Becker believes that the greater part of the gold was deposited at the close of the great Algonkian volcanic epoch; this certainly holds good for the Carolinian belt, and probably for the remainder. Gold-deposition was seemingly renewed with decreasing activity after the Ocoee and the Monroe beds were laid down (Algonkian?). It seems certain that the Triassic beds of the Newark system contain placer-gold, so that veins must have existed before their deposition. With much reason, we may characterize the veins as chiefly post-Archean and pre-Cambrian.*

Future Tendency.—No startling developments may be expected from the Appalachian pre-Cambrian belt, but an output of an average of M^2\$0.5 per year for over 100 years certainly inspires confidence in a long-continued moderate production. As Becker remarks, the veins have suffered great erosion, and the parts worked at the present must have been far below the original surface at the time of deposition. They are the roots rather than the tops of fissure-veins.

British North America.

Statistics.—The total production of gold in British North America is about M^2\$140.2. During the period 1877–1900 the output amounted to M^2\$84.7. It seems convenient to separate

* In a recent short paper E. C. Eckel expresses the belief that the Dahlonega, Georgia, veins are of later age and not earlier than the Carboniferous.

the provinces, which are so different in their geological character. These provinces have produced as follows:

	Total.	1877–1900.
Nova Scotia,	M²$ 13.7	M²$ 9.7
Ontario,	1.2 (?)	1.1 (?)
Quebec,	2.0 (?)	.2 (?)
British Columbia,	70.7	21.1
Northwest Territory,	52.6	52.6
	140.2	84.7

In Nova Scotia, gold-mining has been carried on since 1862, the output varying between M²$0.1 and M²$0.6. During the last few years the average has been distinctly higher than before.

Ontario has increased its production greatly during the last few years, and has now reached an amount between M²$0.3 and M²$0.4 per annum.

The most interesting statistics are those of British Columbia. Placers were discovered on the Frazer river in 1857. The recorded output began in 1858 with M²$0.5. In 1860 the Cariboo district began to produce, and the production rose to a maximum of M²$3.7 in 1864. From this time it sank steadily to M²$1.4 in 1874, rising again to M²$2.5 in 1875, owing to the discoveries of the Cassiar fields. Then sinking again, the production was less than M²$0.4 in 1893. At this time profitable lode-mining began in the southern part of the province, at Rossland and other places, while the placers yielded about as before,—*i.e.*, M²$0.5 per annum. In 1895 the total was M²$1.3. In 1900 the output of British Columbia was M²$4.7, of which amount M²$1.3 was derived from placers and M²$3.4 from lode-mining. The increase in placer-gold was chiefly due to the newly discovered Atlin mines, in the most northerly part of the province.

The Northwest Territory contained few mines previously to the discovery of the Klondike district in 1897. The annual maximum output from 1885 to 1896 only reached M²$0.35.

From 1897 we note the rapid increase as follows:

1897,	M²$ 2.5
1898,	10.0
1899,	16.0
1900,	22.3

Geological Features.—British North America possesses at least two principal gold-bearing areas, the deposits of which are of widely differing age.

The deposits of Nova Scotia, Quebec and Ontario are gold-quartz veins with auriferous pyrite and native gold. They occur in Cambrian (Nova Scotia) or Algonkian (Ontario) rocks. Becker regards the Nova Scotia veins as pre-Carboniferous, and cites an interesting occurrence of a gold-bearing conglomerate—an old placer-bed—of lower Carboniferous age. McKellar states that the Ontario veins occur in Archean rocks only, and not in younger strata.

The eastern slopes of the Rocky Mountains in Canada do not contain many deposits of importance, but in British Columbia and Northwest Territory are scattered many rich districts. Along the southern coast, on Vancouver Island, are gold-quartz veins of doubtful age in old rocks. Along the southern boundary-line, in the Kootenay districts, considerable placer-work has been done, and veins occur in rocks of Mesozoic or older age. Many of these are smelting-ores associated with values in copper (Boundary, Rossland), and the veins are contained in Paleozoic or Mesozoic rocks. Others carry quartzose, partly free-milling ores like the Ymir and Athabasca veins, but this type is more rare.

The important Cariboo district, in central British Columbia, contains many gold-quartz veins in schists probably Paleozoic, which, however, have as yet been little worked. The very extensive placers were discovered about 1858, and have yielded since then more than M^2\$35.0. The placers are largely of Miocene or Pliocene age, but Bowman states that a basin of Lower Cretaceous rocks in the Quesnelle Valley contains workable placer-deposits. The age of the primary deposits is thus Cretaceous or pre-Cretaceous. The fact that the Lower Cretaceous rocks contain placers would make the age of the primary deposits most probably early Mesozoic and somewhat earlier than the California gold-quartz veins. The placers at Omineca, Liard River, Cassiar and Atlin appear to be derived from deposits of about the same age as the Cariboo veins. On the whole, it seems most likely that this whole gold-belt of British Columbia is of Mesozoic age, and should be regarded as the northward extension of the California and Oregon belt.

Northwest Territory, in former years a slight producer of placer-gold, has lately derived great importance from the discovery of the Klondike gravels. The gold is, according to McConnell and Spurr, derived from veins in a metamorphic

series of Paleozoic age. The veins have thus far been disappointing, not corresponding to the richness of the placers. Similar conditions obtain at several of the great placer-camps of California, Oregon and Idaho. The placers are regarded as Pliocene, and the veins are thus pre-Pliocene and Paleozoic or post-Paleozoic. Gold veins of post-Miocene, propylitic type seem entirely absent from British North America.

Distribution.—In the eastern belt of pre-Cambrian veins, practically the whole output is derived from quartz-mining.

In the British Columbia belt the whole output up to 1893 should be credited to the placers. From 1893 to 1900, inclusive, the lode-mines along the southern boundary produced M^2\$12.8. As to age, the whole production of British Columbia and the Northwest Territory should probably be credited to primary deposits of Mesozoic age. In the figures given for more remote years the silver is included with the gold, but the amount of the former metal is very small.

Future Tendency.—The deposits of Nova Scotia have shown great constancy of production. If the Ontario deposits will exhibit similar characteristics, we may expect for many years a well maintained, though probably not very much larger, production than the present.

British Columbia may not maintain its placer output of last year; but the lode-mining has of late shown great activity and the resources of the country are just beginning to be known. Although a few of the shoots worked have been disappointing as regards permanency, there are others coming in, and the present output will probably be maintained for many years and possibly very greatly increased.

The placers of the Klondike have probably passed their zenith, if comparison with the history of other districts is of value. But, as McConnell remarks, the amounts remaining will insure a high production for many years, especially if improved methods be used. New placer-discoveries are not at all impossible.

Mexico.

Statistics.—Mexico is chiefly known for its great production of silver, but it produces also a considerable amount of gold, and the output during the past few years has shown a remarkable, rising tendency. Ever since the Spaniards began to work the mines of Mexico in the 16th century a gold-production has

been maintained, but the exact figures cannot be obtained. The reported production of gold from 1690 to 1865 is $\mathrm{M}^2\$103.0$, but this, of course, does not represent the full amount. During the period from 1865 to 1895 the output is believed to have been $\mathrm{M}^2\$30.0$, or approximately $\mathrm{M}^2\$1.0$ per annum. From 1895 on, however, the estimates of the Mint Bureau show a great increase. In 1895 $\mathrm{M}^2\$6.0$ represented the production, and in 1900 this had increased to $\mathrm{M}^2\$9.0$.

The total Mexican production since 1690 is at least $\mathrm{M}^2\$180.7$, while the production from 1877 to 1900 is believed to be about $\mathrm{M}^2\$66.5$.

Geological Features.—For many years the gold in Mexico has been derived as a by-product from the great silver-mines of the central plateau, which chiefly appear to be of post-Miocene age. The principal region of the gold-ores lies, however, along the western coast of Mexico in Lower California, Sonora, Sinaloa, and even farther south, and it is largely from this region that the output of recent years is derived.

Messrs. Aguilera and Ordoñez divide the gold-deposits of Mexico as follows: The first group, scarcely known in the United States, occurs as contact metamorphic deposits, associated with copper-ores between diorite and Cretaceous limestone. A considerable amount of gold has been derived from these deposits, chiefly occurring on the slopes of the eastern Sierra Madre. Their age is most likely Cretaceous or early Tertiary. Such deposits exist at Encarnacion and San José del Oro, State of Tamaulipas, at Mazapil, State of Zacatecas, and even as far south at Santa Fé, State of Chiapas.

The second group consists of fissure-veins in older rocks, and contains gold-ores with but little silver. They occur in scattered form in Lower California for 300 miles south of the boundary-line, at Santa Clara, Real del Castillo, and even down to San Borja and Calamahi. In Sonora they appear in the Altar, Magdalena, Minas Prietas and many other districts. The encasing rocks are usually granite, pegmatite or old schists.

According to Mr. J. E. Curle,* the two principal mines at Minas Prietas are the Grand Central, and the Creston and Colorado, the latter producing at the rate of $90,000 per month. It is the largest producer in Mexico, next to El Oro. This gold-

* *Gold-Mines of the World*, London and New York, 1902, p. 335.

belt continues through Sinaloa, Tepic, Jalisco, Guerrero and Oaxaca.

The third great division is formed by the gold-silver veins in andesites and trachytes occurring chiefly along the western slope of the Sierra Madre. According to W. H. Weed, such veins occur in andesite, below heavy masses of barren dacite and rhyolite, at Guadaloupe y Calvo in the southern corner of Chihuahua and at La Cumbre in the adjacent part of Sinaloa. In this vicinity are also located the veins of San José de Gracia, which, according to Ordoñez, are heavy producers at the present time. Similar deposits are described from Cerro Colorado, Chihuahua, from Taviches, Oaxaca, from El Mesquital de Oro, Zacatecas, and many other places. Curle states that the heaviest producer of gold at present is the El Oro, State of Mexico, 100 miles northwest of the City of Mexico. The veins are said to occur in andesite and in Mesozoic sediments.

Lastly, there are the great silver-veins of the central plateau, which contain a little gold, and which in the aggregate have yielded a great amount. They, too, occur in connection with Tertiary andesites.

It is likely that the gold-deposits of Mexico belong to several different periods. Beyond doubt the gold-belt of Lower California is the continuation of the Mesozoic veins of California, and it is to be surmised that many of the veins from the western belt of pure gold-ores are also of pre-Tertiary age. Prof. Dumble states that many of the gold-veins of Sonora occur in Triassic rocks, and believes that some Triassic conglomerates contain gold. The principal gold-silver belt is clearly of Tertiary age. Ordoñez states that the age of the productive andesites of the western slope of Sierra Madre is late Miocene.

Data for the distribution of the gold-product of Mexico among the different States are not available.

Future Tendency.—Mexico is currently believed to be an extremely well-prospected country; but it is evident, from the developments of the last few years and the rapidly-increasing gold-product, that much still remains to be done in the exploitation of the deposits. It is probable that the next few years will witness a still further increase in the gold-production of Mexico.

The Development of the Bessemer Process for Small Charges.

BY BRADLEY STOUGHTON, NEW YORK CITY.

(New York and Philadelphia Meeting, February and May, 1902.)

SECRETARY'S NOTE.—To avoid repetitions of footnotes, references to authorities are made in this paper by means of figures, referring to a numbered list in the appendix.—R. W. R.

INTRODUCTION.

THE regular, bottom-blown Bessemer converter of the present day is a modification of previous forms, and most of the latest proposed modifications of it are merely returns to former types which Bessemer discarded. That he tried almost every conceivable method of blowing iron, with tuyeres at almost every possible position or angle, is well known; and it is to be supposed that he was familiar with the advantages of each type, since he finally settled on that form which has not been improved upon hitherto, for the purposes for which converters will generally be used.

Modifications have been tried along two lines: In the arrangement of tuyeres, and in the manner of carrying out the process with tuyeres still blowing vertically upward through the bath. While they have all failed in general competition with the regular modern type of vessel, some of them have found special fields in which they have held their own. The most notable example is in the steel-casting industry, and especially in that part of it concerned with the manufacture of castings which require very hot or very fluid metal, or supply a demand of constantly varying physical or chemical requirements. In this industry the small converters occupy a field between that of the crucible-process and that of the open-hearth process, and have won a place for themselves in France, England, America, Russia and other countries, which they bid fair to retain until either a new method is discovered of producing cheaply very hot, fluid steel, or the open-hearth process is so improved that very hot steel may be made with it at lower cost of repairs to lining and roof.

I. Modifications in Arrangement of Tuyeres.

The following modifications, among others, have been made in the manner of blowing the charge.

The Clapp-Griffiths Converter.

The Clapp-Griffiths modification has been so thoroughly described in the *Transactions* [1, 1a, 6, 8, 28] already, and its alleged advantages and disadvantages have been so fully discussed that it might be omitted here, but for the circumstance that subsequent inventors in this line have repeated all the claims of the Clapp-Griffiths advocates, without regard to the results of that discussion. This paper, therefore, would be incomplete without a brief summary of that controversy.

The Clapp-Griffiths type consisted in a small, fixed, side-blown vessel,* having a slag-hole through which some slag was removed at a certain stage of the blow.

The first plant was started in this country in April, 1884[1]; there were no more in operation until January, 1886[6], but 13 were working in August of that year, and 16 by November, 1887; 1 was moved to Mexico, leaving 15 in operation here at the end of 1888[14, 35]. None have been built since 1889[26]; in 1894, only 5 were left in operation; in 1896, the original Oliver plant was dismantled, leaving only 2 converters working, and, for more than three years past, no steel has been produced in these vessels in this country.

Disadvantages of Fixed Converters:—

1. Fixed vessels are mechanically more awkward to handle and less regular in their work than tilting ones.

2. The metal must be tapped out of them at the end of the blow, which takes longer, and is more subject to accidental delays, than to turn down a tilting-vessel. Moreover, at least enough wind must pass through the tuyeres during tapping to prevent metal from running into them, and thus the product is more liable to irregularities in blowing.

3. Recarburizing cannot take place in the converter.

4. Tuyeres cannot be repaired without removing the metal from the vessel.

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* Illustrated in *Trans.*, xiii., pp. 763–6, in connection with the paper by Robt. W. Hunt, on "The Clapp and Griffiths Process."

5. It is difficult to add scrap to cool a hot blow.

6. The basic process cannot be carried on in a fixed vessel, on account of the large amount of slag made, which chokes it up[5].

7. It has been asserted, also, that samples of the bath could not be taken during the blow; but Hardisty speaks of the chemical history of the charge in a Clapp-Griffiths-Bessemer converter[5]; and it is hard to see how he could do so unless he found some means of obtaining samples. R. W. Hunt took several samples during blows. In fact, a slag-hole would appear to give an excellent opening for just this purpose.*

Disadvantages of side- as compared with bottom-blowing:—

1. Bessemer found that, in side-blowing, the wind did not penetrate the bath, but passed up at the sides in big gulps, rapidly slagging away the lining. In blowing from the bottom at high pressure, the blast broke up into a shower of small bubbles[2, 5]. Obviously, the latter result produces much more rapid and uniform oxidation, and less waste of iron or corrosion of the lining.

2. In low side-blowing, some blast must be passing through the tuyeres during the whole time of tapping, so as to keep the metal out of them. This renders it necessary, in order to prevent over-blowing, to tap the charge when it is still "young;" and the accuracy of blowing is notably less certain under such conditions, while any delay during tapping causes the metal to be over-blown. In high side-blowing, on the other hand, the upper part of the bath is subject to greater oxidation than the lower part. In either method, the outer portion of the bath is blown before the center, and the steel when tapped is liable to be heterogeneous.

3. In side-blowing (and especially in high side-blowing), the oxidized iron can reach the lining or the slag without first being brought under so strong or so long-continued a deoxidizing influence as it is in bottom-blowing; and thus the waste will be greater through the formation of more slag by corrosion of the lining, and through the carrying of more iron into the slag.

4. In high side-blowing, some free air may escape from the bath without having done the work of which it is capable,

* Of course, it is not possible to take and test samples, and, if they are not right, begin the blowing again and continue it to the proper point.

causing a more highly oxidizing atmosphere inside the converter, and, therefore, more waste, and also making the time of blow longer. Even in bottom-blowing, the air does not always lose all its free oxygen in passing through the bath (see Table XX.); some is found in the gases from the converter; and this waste will be the larger, the higher the tuyeres are placed.

5. The use of the spectroscope in connection with side-blowing is said to be utterly worthless[5], probably because, for the reason last given, the atmosphere in the vessel is an oxidizing one.

Alleged Advantages of this Type of Converter:—

The following claims were advanced by its advocates, and have been persistently repeated by others in behalf of inventions possessing similar features.

1. A better quality of product was claimed, by reason of:

(*a*) Greater Uniformity in Analysis.—This claim, advanced by Hunt in discussion, was disproved by Howe (at least so far as carbon was concerned), who showed that Clapp-Griffiths steel varied several times as much as regular Bessemer. Table I. summarizes these results. As to relative uniformity in silicon, we lack sufficient figures for the Clapp-Griffiths steel to make an equally definite comparison. Table II. shows that regular Bessemer steel is very uniform in silicon, and may be made uniformly low if desired. The variations, in fact, are so extremely small that it does not seem possible that they can have an appreciable effect on the physical properties of the steel. No steel can claim superiority to Bessemer in this respect unless the claim is strongly backed by both analyses and physical tests.

(*b*) Greater Softness of the Metal.—In England, France and America, the Clapp-Griffiths converters were used almost exclusively for the production of the softest grades of steel, and they seemed to be able to remove quite uniformly all but the last traces of carbon and silicon. The product was said to be always mild, ductile and weldable[4, 6, 7, 8, 27]. But when the further claim was made that this constant softness of product and elimination of silicon could not be regularly obtained by any other process, objections were at once raised. Dr. R. W. Raymond gave the results of analyses made by the Trenton Iron Co., of Bessemer steel bought from the Bethlehem Steel

Co. (see Table III.), to show the uniformity and low silicon of soft, regular Bessemer steel[6]; Mr. E. F. Wood published analyses (see Table III.) selected at random from the ordinary stock of the Homestead Steel Works' soft Bessemer metal, and asserted that the regular Bessemer converter could produce steel even lower in silicon, and quite as uniform as was claimed for the Clapp-Griffiths, and that the Homestead Steel Works had no difficulty in keeping that metalloid below 0.01 in low-carbon steel, and below 0.02 in steel of 0.12 to 0.15 per cent. carbon,—its elimination depending on the temperature of the process[29]; and Mr. S. McDonald claimed that the regular Bessemer converter could get all the advantages of low silicon that were to be had, and quoted analyses of nail-plate from the Riverside Nail Co. in support of this assertion[30].

The claim in favor of the Clapp-Griffiths was that the tapping off of slag effected the uniform removal of silicon, the argument apparently being that taking away the slag prevented reversion of the silicon in it back into the metal. Hardisty, however, declared that, in the metal from a small converter, silicon was always low when carbon was low, whether the slag was tapped off or not, and, moreover, that the Clapp-Griffiths practice never tapped off all the slag[5, 5a]. But even if all the slag present at the time of tapping (that is, at the first part of the boil) was removed, new slag would form all the time, on account of inevitable oxidation of iron and corrosion by it of the vessel-lining, and the amount of silicon in this slag would always be far greater than would represent a large proportion of silicon in the bath. Hence, there seems to be no reason to think that the removal of the silicon first taken from the metal would necessarily prevent reversion of other silicon back into the bath later—supposing, for the sake of argument, that such a reversion were possible, instead of being, on the contrary, opposed to reason and experience.

Tables IV. and V. show that, while the silicon does not oxidize as fast after the carbon begins to burn, yet it does constantly leave the iron during the whole of the blow. All of the examples given in these tables are of regular Bessemer practice, in which no slag is removed; and it is reasonable to suppose that, if silicon is being oxidized all the time, reversion is a thing not to be feared.

If the slag ought to be removed to prevent reversion of its silicon into the bath, the time to remove it would be towards the last of the boil, and not at the beginning. All the slags of Table IV. have a larger proportion of iron oxide at the beginning of the boil than later, because of reduction by carbon. In other words, the later slags in the Bessemer process are less retentive of silicon than the earlier, because they contain a smaller proportion of basic iron oxide to hold it. Moreover, in removing the early slags we are removing iron oxide, which would otherwise be reduced and be saved as iron. The higher waste of iron in the Clapp-Griffiths modification is, undoubtedly, due in part to this removal of rich slag.

2. The possibility of using cheaper iron as raw material was claimed for the Clapp-Griffiths process. It was asserted that, because of the lower silicon, the tapping of slag and the low pressure of blast, steel from the Clapp-Griffiths vessel could contain more phosphorus than any other steel and still be safe and useful[6]. But Table VI. shows that other steel may be equally high in phosphorus and still give good tests. It has been shown before that steel low in carbon may contain high phosphorus without much damage to its physical properties; but such steel is always treacherous[17, 32].

Other Modifications.

Among other modifications proposed, the following may be briefly mentioned. They did not receive so much attention as was given to the Clapp-Griffiths.

Durfee.—In 1863–4, Z. S. and W. F. Durfee erected a stationary converter* at Wyandotte, Michigan, in which only a few heats were ever made[8, 12].

Wittnoefftt.—The Wittnoefftt converter (1878), likewise earlier than the Clapp-Griffiths, was a stationary vessel with fixed bottom. It was similar in design to Bessemer's converter, used at St. Pancras (see Fig. 1), and to the earlier Swedish converters (see Fig. 2), and, as in them, the tuyeres were pointed so as to give a rotary motion to the bath. But this was later changed on account of the heavy wear it caused in the lining. The vessel had 4 tuyeres on each side, pointing downward[5, 25].

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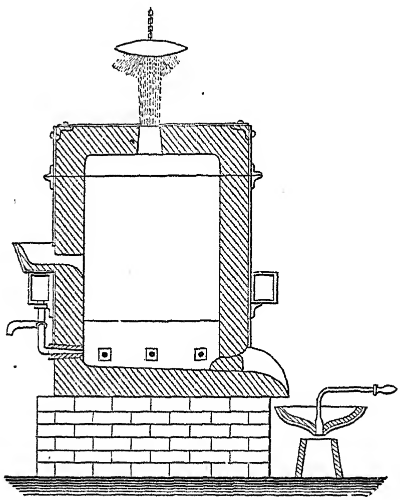
* Illustrated, *Trans.*, xiii., 771.

Thomas.—Sydney Gilchrist Thomas (1882) proposed to secure the advantage of the cheapness of the fixed converter, by saving the cost of the expensive tilting-apparatus, and still to retain the advantages of the tilting-type, by mounting a vessel on rockers, on which it would oscillate with a very slight force, exerted either by hand or power. He preferred an elliptical section, with the longer axis parallel to the rockers, and tuyeres 1 in. or more in diameter, only on the side opposite to the tap-hole. The line of tuyeres was to be parallel, or inclined, to the bottom. In the latter case, the vessel was to be inclined in the opposite direction, so that all the tuyeres might be at the

Fig. 1.

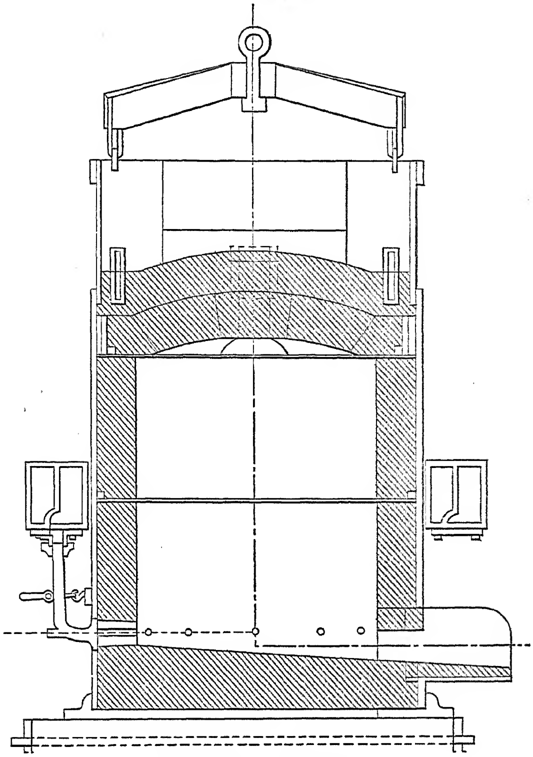


Bessemer's Converter, St. Pancras, 1856.

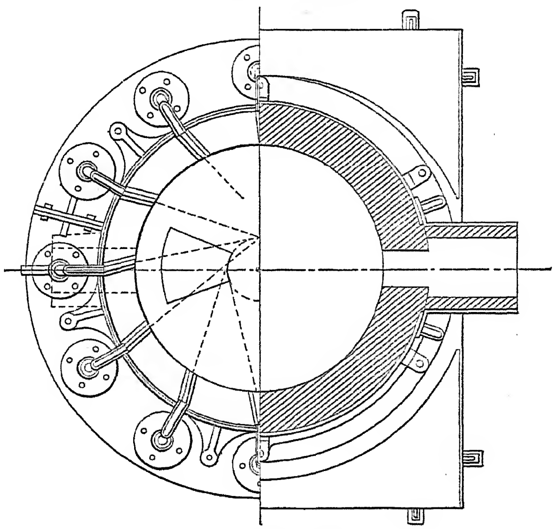
same depth below the surface, although it was also allowed in the specifications to "turn the vessel into such a position that, while the majority of the tuyeres are blowing under the metal, one or two are blowing across the surface, so as to consume rapidly the carbonic oxide liberated." When the blow was finished, the vessel was turned so as to bring the tuyeres all above the surface of the metal, and the charge was tapped[43]. This modification is described here, because it seems to have anticipated some later inventions.

Murdock.—W. M. Murdock (1883) suggested a tilting-vessel with tuyeres all around the sides, and a "receiver," so placed

Fig. 2.



Elevation and Section.



Plan and Section.

Early Swedish Fixed Converter.

that it would be above the level of the metal during the blow, but when the vessel was turned down the charge would run into it, to be removed through a tap-hole. This receiver was either a bulged-out portion of the vessel, or a separate chamber connected by a passage. If desired, there could be a receiver on either side[44].

Brooke.—The E. & G. Brooke Iron Company, of Birdsboro, Pa., put into its works (1885) a tilting-converter with 4 tuyeres from 6 to 7 in. from the bottom. The charge was 2,600 lb., and lay entirely clear of the tuyeres when the vessel was turned down on either the receiving- or the pouring-side. The blast-pressure was 7 lb. per sq. in. The converter was described as a Clapp-Griffiths[45].

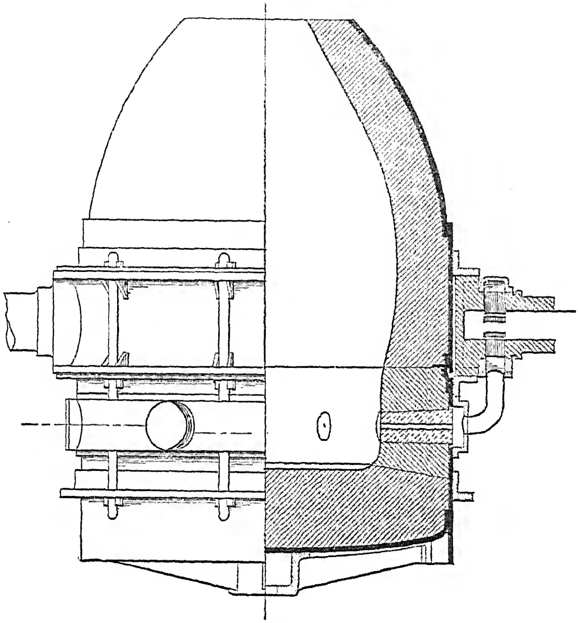
Laureau.—L. G. Laureau (1887) also had the tuyeres placed high, but, on account of the excessive wear of linings at the mouths of all tuyeres, he placed them in a separate ring of the lining, so that they could be replaced without changing any other part of the vessel. This was a tilting converter, and there were no tuyeres in the front, so that it did not have to be tipped through a very large angle to bring the tuyeres above the bath[5, 16, 46]. (See Figs. 3 and 4.)

The Walrand-Delattre or Robert Converter.

About 1884, a Clapp-Griffiths converter was erected at Stenay, near Paris, France, under the direction of M. Charles Walrand, formerly of Creusot[4, 34]. In order to employ also the basic process, M. Walrand shortly afterwards designed and erected two little tilting-converters, to which he gave the name of "Walrand-Delattre," and, at the same time, two similar ones were erected under the direction of M. Servais, at the Hollerich works, in Luxembourg[47, 48]. These converters were not unlike one said to have been proposed by M. Henri Harmet, of Creusot, some years before[34]. At the Stenay works, though erected for the basic process, they were at first used only for low-phosphorus irons; but the Hollerich plant treated basic irons from the beginning of its operation, June 12, 1885 [47, 48]. Some analyses from there are shown in Table VIII. The converters were of 2-tons capacity each; one was lined with acid-, and the other with magnesia-bricks. The iron was run direct from an elevated cupola into the acid-vessel, where

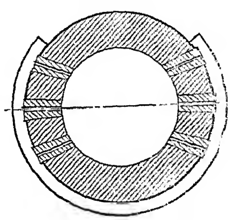
it was blown until the carbon was eliminated, and then transferred in a ladle to the basic vessel, which was on a level 10 ft. below the acid-vessel, and into which 7 per cent. of limestone

FIG. 3.



Vertical Elevation and Section.
Laureau's Converter.

FIG. 4.



Horizontal Section at Tuyeres.
Laureau's Converter.

had been previously charged. The time of blow was about 13 min. in the acid-vessel and 4 min. after-blow in the basic vessel[47]. In later practice, the total time of blow and after-blow was 12 min.[5]. The blast-pressure was 4 to 5 lb. per sq. in.

One per cent. of ferromanganese was used for recarburizing, the steel (used for small castings) being very soft and hot. In spite of the low manganese in the pig, the slag was very fluid [47]. Two to three blows per hour were made and the lining lasted, on the average, 60 heats. The loss was said to be from 18 to 20 per cent.[5, 47]. Later, the linings lasted from 80 to 90 heats, and the tuyeres 25 heats, without repairs; after which they had to be repaired every 8 or 10 heats[51].

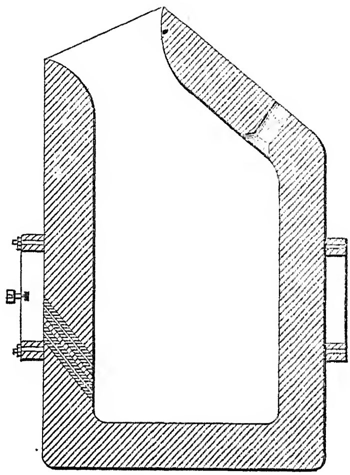
At the Stenay plant, acid-work was begun March 13, 1885. The analyses of iron and steel are shown in Table VIII. The steel was used for castings. The time of blow was from 18 to 20 min., and 16 heats were made in 12 hours regularly, the coke-consumption in the cupola being 12 per cent. of the iron melted. The loss was said to be 16 per cent. The vessel-lining lasted about 220 heats and the tuyeres 90 heats. The latter were formed by ramming refractory material around wooden plugs[5, 47]. Later linings lasted from 800 to 900 blows, but had to be repaired near the tuyeres after every 80 to 90 blows. The tuyeres were then (1887) made by cutting holes in the bricks of the lining[51]. The cost of making steel in this converter, according to M. Steffen, was a little over $2 per ton more than in the regular Bessemer converter[9].

The converters originally erected are shown in Figs. 5 and 6; and this form was patented by Charles Walrand and A. Delattre, February 16, 1884 (French patent, No. 160,379).* It will be seen that, like most of its predecessors, it was circular in horizontal section. When turned down for pouring, the metal lay just clear of the tuyeres. The tuyeres were pointed at such an angle as to give a rotary motion to the bath during the blow, in order to avoid the localized blowing common in side-blown vessels, or, expressing the same thing in different words, to bring every molecule of metal in the bath under the direct action of the blast. This scheme had previously been adopted in the early Swedish fixed vessels, and others, as noted above. A later form of converter is shown in Figs. 7 and 8.

After the Stenay works were erected, M. Gustave L. Robert became the manager, and changed the form of the converter by making the back a plane parallel to the axes of the vessel

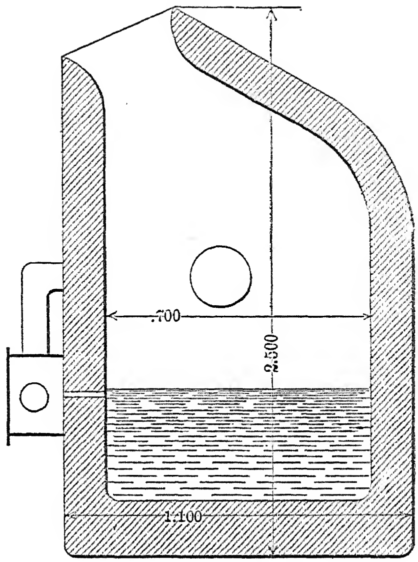
* A converter greatly resembling this was patented in Germany, April 30, 1884, by Philip Lamberty[49].

FIG. 5.



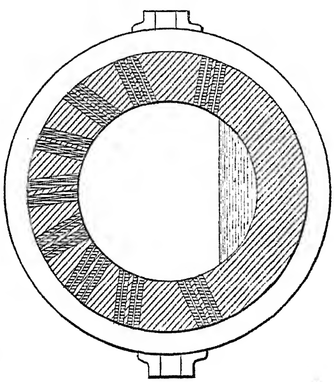
Vertical Section.

FIG. 7.



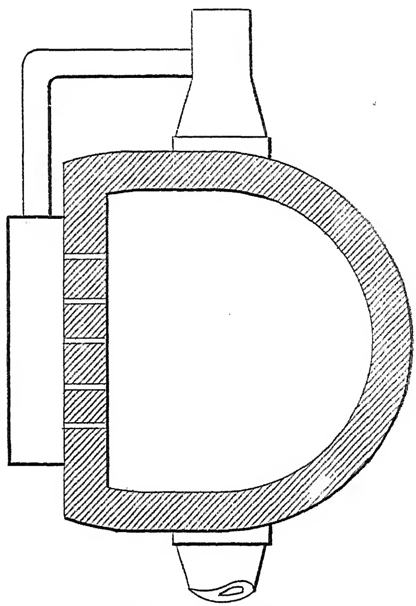
Vertical Section.

FIG. 6.



Horizontal Section.
The Walrand-Delattre Converter
of 1884.

FIG. 8.



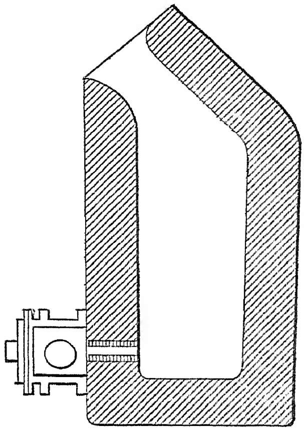
Horizontal Section.
The Walrand-Delattre Converter of 1887.

and the trunnions. He adopted and patented two forms shown in Figs. 9 to 13, but the form shown in Figs. 11 and 12 was the one most commonly used thereafter. His patent was taken out May 3 and June 6, 1885 (French patent, No. 168,896), and gave no credit to M. Walrand for his work[50, 18]. Evidently, M. Walrand objected to this treatment, but we are told that an agreement was reached between them, as otherwise the patents might have become worthless to both. Thereafter, however, the business was continued in the name of Robert[50], although Walrand still claimed to be the inventor[51].

The Robert tuyeres were horizontal and always placed in the flattened plane of the back. They retained the direction, slightly inclined to the radial, of the original Walrand vessel; and, in fact, the only novelty introduced by Robert appears to have been flattening the back and placing the tuyeres in the plane surface so formed. M. Walrand had planned the level of the tuyeres so as to bring them not over 4 in. below the surface of the bath, with the object of allowing some of the air to escape from the metal unconsumed and burn the carbon monoxide, generated by the action of the blast on the bath, to carbon dioxide, thus obtaining a higher temperature. This idea was not new with M. Walrand, but had been followed by the Bessemer men in America since 1880, or before, in the practice known as "side-blowing for heat," in which the bottom-blown vessel is turned over until some of the tuyeres are near the surface, or even emerge from the bath, blowing unconsumed air into the interior of the converter. It is also mentioned in the patent of Thomas referred to above.

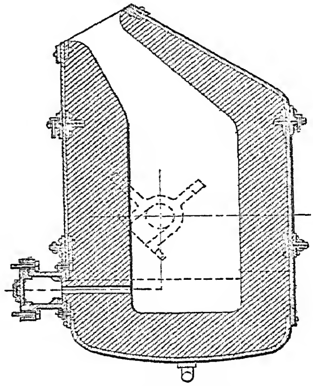
The gain in heat thus secured cannot be questioned, as a simple calculation will show. If the pig contains 3.5 per cent. carbon, a 2-ton charge will contain 156.8 lb. of carbon, which will generate 7,100 calories in burning to carbon monoxide, in excess of the calories used up in raising the air consumed to the temperature of the bath (assumed at 1615° C.). If, however, the carbon is burned to carbon dioxide, it will generate 200,500 calories in excess of those absorbed. The claim was advanced at Stenay that the gases were higher in carbon dioxide than those from the regular Bessemer converter, but the only evidence offered in support of this claim was, that the steel was hotter[53].

Fig. 9.



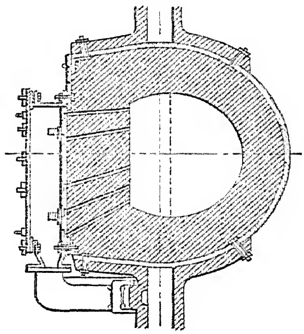
Vertical Section.

Fig. 11.



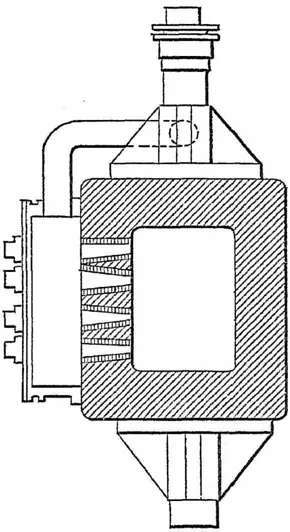
Vertical Section.

Fig. 12.



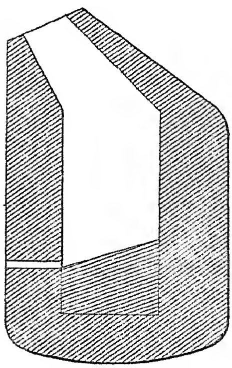
Horizontal Section.

Fig. 10.



Horizontal Section.

Fig. 13.



Vertical Section.

Various Forms of the Robert Converter

The practice of higher oxidation of the gases has, however, its disadvantages also, since it necessarily produces an oxidizing atmosphere inside the converter, which causes greater waste of iron. In his early experiments, Bessemer tried blowing on, or near, the surface of the bath, and noticed that, whenever doing so, he burned a large amount of iron, as indicated by the excessive quantity of slag formed and the dense brown smoke given off. The lower the tuyeres were placed, the less this was noticed, whatever the shape of the vessel used[52]. A second disadvantage is, that it takes twice as much air to produce carbon dioxide as to produce carbon monoxide, and, therefore, the blowing mechanism has twice as much work to perform to burn off the carbon.

The higher temperature is necessary in small vessels, or for making small castings as a regular practice, since the radiation is great in proportion to the size of the charge.

Robert Linings—Basic.—In 1889, the lining of the bottom and sides of the basic vessel at Stenay was made of dolomite as low in silica as possible, which had first been calcined and powdered and mixed on an iron plate, by means of a shovel, with 25 per cent. of hot coal-tar absolutely free from water, and then intimately mixed in a mixing-apparatus. If properly made, it should not fall into powder when squeezed in the hand. It must be kept free from moisture. This is called the thin mixture. The rest of the vessel was lined with the calcined, powdered dolomite, mixed with 10 per cent. of tar. The mixtures were either rammed in around a suitable pattern, or made into bricks of the proper shape by hydraulic pressure, and laid in with a mortar made of the thin mixture given above. Of the two, the brick-lining stands wear better. The shape of some of the bricks for a 1-ton vessel is shown in Mr. Garrison's paper[52]. A patching-mixture is made of from 1.5 to 2 parts of hot tar to 4 parts of dolomite[52]. The analysis of the dolomite is given in Table IX[53].

Robert Linings—Acid.—The acid-linings may be made of bricks or rammed up around a pattern. In either case the material must be very refractory, on account of the high temperature of the operation. Bricks must not be friable, or they will break up in contracting and expanding with the heat, or be rapidly abraded by the action of the bath. A good compo-

sition is that given in Table IX. Two shapes of bricks for a 1-ton vessel are shown in Mr. Garrison's paper[52]. The length of the curved brick may be changed according to the desired thickness of the curved part of the lining. The flat bricks are for the bottom, back, etc. All must be laid with very thin joints of very refractory mortar. This requires skilled labor and time, and the rammed lining is therefore cheaper, and preferable, if good refractory clay can be obtained.

The bottom is first constructed, and is 10 to 11.5 in. thick, the essential feature being that its upper surface must be horizontal and 11.5 in. below the level of the axes of the tuyeres. Sand is first rammed in, and then two courses of brick are laid flat[52]. If the bottom were all rammed up, the metal would be liable to work a way under it and force up portions, leaving large holes. If this happened during a blow it would lower the level of the upper surface of the bath and be inconvenient. Moreover, in drying a rammed lining, the escaping steam would be liable to loosen portions of the flat surface and cause them to "spall off," unless it was securely nailed in the manner employed with large, plane surfaces in molds. But putting on the upper courses of bricks avoids these difficulties.

On the bottom, made as above, is placed the pattern for the lower half of the interior of the converter.

The refractory material is rammed around the pattern with red-hot rammers, in successive layers not over 1 in. thick. When the level of the tuyeres is reached, mandrels are laid in and the material rammed around them. When the top of the pattern is reached, another one, exactly like it, is placed on top of it, and the ramming continued until the level of the nose is reached. The nose should have been previously removed and rammed up separately in the inverted position[52].

Acid-linings last over 1,000 heats with slight patching[53]. This figure, together with all the above description, refers to the practice at Stenay in 1889.

Robert Tuyeres.—The converters at Stenay, in 1889, were of 1.25-tons capacity each. The acid-vessels had five $1\frac{3}{8}$-in. tuyeres; the basic, six $1\frac{1}{8}$-in. tuyeres[53]. When the capacity of the converter is increased the number of tuyeres is increased and the blast-pressure kept practically the same. The angles of the tuyeres to the flat surface of the back are as follows:

90°, 85°, 80°, 75°, 70° (65°). When the linings were of brick the tuyeres were always made of brick and laid in; when the linings were rammed up the tuyeres were sometimes made of brick and laid in, and sometimes rammed up around mandrels as described. Their axes must all be in the same plane, which must be horizontal in both directions when the converter is vertical. When worn they may be repaired by laying the vessel in the horizontal position, with the back, or tuyere side, underneath, throwing balls of mortar onto the inside of the tuyeres and beating them down with an iron peel, and then cutting holes in the patching thus formed of the size of the holes in the tuyere. They must then be dried for from 15 to 20 min. After this repairs must be repeated every 4 to 5 blows.

Brick tuyeres are $18\frac{1}{8}$ in. in length and slightly tapering outwards, so as to be more readily withdrawn and replaced when worn out[52].

Operation of the Roberts Apparatus.—Some chemical analyses of the pig used at Stenay are given in Table XII., and charges for two months are shown in Tables X. and XI., which have been calculated from the paper by Garrison[52].

The iron may be melted in a cupola or taken from a blast-furnace direct; but, in either case, it is essential that it come to the vessel physically hot[52]. At Stenay, and in general at Robert-Bessemer plants, it was remelted in a cupola. Robinson gives the Stenay cupola fuel-ratio as 1 to 5.44, the fuel being coke with 10 per cent. of ash and 0.04 per cent of sulphur[53]. The following description refers to the Stenay plant:

A sufficient quantity of molten iron is used to bring the upper surface of the bath to about the same level as the tuyeres, when the vessel is in the vertical position. It may be brought by means of a ladle, or run in direct from the cupola through a trough. In the latter case, the converter is placed nearly upright, and the wind turned on when it is judged that the upper surface of the metal is 1 in. below the tuyeres. A great quantity of sparks is given off, which gradually diminishes as the vessel is turned back towards the absolutely vertical position, until the metal reaches the level of the tuyeres, when the sparks increase again in volume and the sound made by the blast becomes duller. The wind is now penetrating a thin

layer of metal. The supply of iron is at once cut off, and then the blast is stopped for a moment, that the "lighting" may be properly accomplished.

Now, the action of the blast gradually produces a rotary motion of the bath, as shown by the spiral motion of the sparks at the mouth. When this action is well established, the vessel is tipped back a little to bring the tuyeres lower down, though it is claimed that the wind does not even then blow through the metal, but piles the iron up in front of the tuyeres in the manner shown in Fig. 13. It is desirable that the air should not penetrate the metal deeply, but only impinge on its surface; and the blast-pressure is just sufficient to produce the rotary motion and to "keep the slag out of the metal."*

The blast-pressure may be controlled somewhat by tipping the vessel back and forth, so as to raise or lower the relative level of the tuyeres, but it should also be capable of being controlled by a valve, and should be, on an average, about 3 or 4 lb. per sq. in. If it is higher than this, the blow is not shortened much and is cold, and the loss is increased;† if lower than 3 lb., the blows are longer and difficult to manage. Even with converters larger than 1-ton capacity the pressure should be about 4 lb. It is very advantageous to be able to regulate it for the different periods of the operation, and for different weights of charge. If the silicon in the bath is low, the average height of metal above the tuyeres‡ is decreased by tipping the converter forward, and the pressure thus reduced,

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* What is meant by the last statement I am at a loss to understand. It would certainly be very hard to *prevent* the slag from keeping out of the metal, if it were desired to do so, since gravity alone separates them very perfectly as long as the bath remains fluid, and it is difficult to see what the blast-pressure has to do with the matter. Of course, there is a contact between metal and slag, and the blast may lessen the area of this contact by driving the superincumbent slag to the leeward side of the vessel and holding it there; but this is apparently not what is intended by the claim. The point is discussed more fully further on

† Presumably the blow is cold, because too much cold air is introduced to suffice for the reactions, and it therefore cools without performing its share of the combustion. The loss is apparently increased by the pressure being so great as to cause excessive spitting.

‡ Since the metal is supposed to be piled up in front of the tuyeres, the "average height of metal above the tuyeres" means the height it would have if the blast were shut off.

the period of decarburization being correspondingly lengthened and the temperature of the blow raised.*

During the first part of the blow there is no flame, but many sparks, which finally diminish and change color, and then the converter is turned back slightly until a flame appears. When the flame is strong, the converter is turned further back until the orifices of the tuyeres are from 1.5 to 2 in. below the average level of the upper surface of the bath. The first period of the blow lasts from 7 to 8 min., and the next from 3 to 4 min., when there is a distinct "drop" to the flame. It shortly reappears, however, and becomes very large. At a second drop, which comes about 1.5 to 2 min. after the first, the blow is completed, and the vessel is turned down and the recarburizer added, unmelted, either in the converter or in the ladle. Ten minutes is allowed for it to melt and disseminate before pouring the steel[52].

Analyses of acid and basic slags are given in Table IX. In appearance, the acid-slag is clear and vitreous, showing a lower content in iron oxide than that of the regular Bessemer process.

As a rule the blows are quiet. It is said that the metal is not so prone to boil as soft metal from the bottom-blown vessel; and it is extremely fluid, by reason of its high temperature[53].

Acid Loss.—M. Walrand places the loss in the acid process (including that of the cupola) as 16 per cent.[51]. Robinson says that, at Stenay, they estimate the cupola-loss at from 3 to 4 per cent., and that the total loss from pig to steel was[53]: in March, 1889, 13.2; in April, 1889, 13.1; and in May, 1889, 12.7 per cent. Hardisty gives 16 per cent. as the total loss[5]. Goetz gives the same figure for the Walrand-Delattre modification in 1885 [47]. Vogel says, figures have been shown him which reach 25 per cent. loss[54].

Basic Loss.—Walrand places the loss in the basic process (including cupola) at 20 per cent.[51]. Robinson says that, at Stenay, they estimate the cupola-loss at 3 per cent., and the total loss was[53]: in March, 1889, 12.8; in April, 1889, 16.1; in May, 1889, 14.9; and in June, 1889, 15 per cent. Hardisty

* Because the oxidizing influences are stronger on account of the tuyeres being relatively higher.

gives 20 per cent.[5]. Goetz gives 18 to 19 per cent. for the Walrand-Delattre in 1885[47].

Advantages of the Robert Converter.—It is an admitted advantage of this form that the steel is somewhat hotter than regular Bessemer metal, and that castings made from it are, therefore, relatively freer from blow-holes[53].

M. Robert claims also that the steel is freer from impurities and, therefore, softer,—which is due, he says, to the avoidance of any mixing of metal and slag or metal and gas during the blow. In this he simply goes a step farther than the Clapp-Griffiths advocates, who claimed only to avoid mixing metal and slag together. M. Robert asserts that, by his rotary motion, he brings all the metal successively under the influence of the blast, without any mixing of the two together, and that he holds the "impurities"* over in the leeward side of the vessel where they cannot do any mixing with the metal. But the advantage of these precautions is not clear. The proof that some new and useful results are obtained with his apparatus should naturally precede the reasons advanced to explain such results. The discussion over the Clapp-Griffiths claims are still too fresh to permit the acceptance of new claims uncorroborated by substantial evidence, by which is meant large numbers of comparative analyses, or results of tests, rather than the opinion of any man, however sincere or eminent.

The tests shown in Table XIII. have been published, but, although good, do not show anything really new.

According to the generally-accepted theory of the Bessemer operation, it should be a positive disadvantage to avoid mixing metal, gases and slag together. With the iron present in overwhelming excess, the blast cannot be expected to pick out all the impurities for complete oxidation, and not oxidize a large amount of iron at the same time,—a much larger amount than is present in the slag during the blow. Mr. Stead said he found that the blast oxidized every element in the molten mass in the ratio in which it existed there, and that the oxidized iron, mixing with the remainder of the bath, oxidized the silicon, manganese and carbon. When he blew air on the surface of a bath, he saw a stream of iron oxide flowing away from

* That is, apparently, oxygenated metal, and slag.

the tuyere, and, collecting this, he found the elements present in it in the same proportion as in the main mass[2]. Further evidence of the very rapid, almost instantaneous, formation of iron oxide is seen in the corrosion of the lining of a converter, since, no matter what form of converter is used, the greatest corrosion is found at the very mouths of the tuyeres, which corrosion is, undoubtedly, due to iron oxide, not of silicon or carbon.

The best Bessemer practice is, of course, to provide that all the iron oxide formed shall be submitted to as strong and long-continued a reducing action as possible before it reaches the lining, which it corrodes, forming slag. Even after this it should be kept under reducing influences as far as possible, since slag itself may lose iron by reduction,* though it is not as readily reducible as the pure oxide. The only available reducing influence present is the bath itself, and, by mixing the oxidized metal and the slag, with the bath, it will be, at least in part, reduced and saved, and will aid in the work of purification.

The Robert Modification in France.—Herr Carl Rott says that the Robert modification has extended more than any of the

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* Åkerman pointed out this action and gave the Swedish analyses of metal and slag in Table IV. in support of the contention. He stated that the lower proportion of iron oxide in the slags at the middle of the blow, especially in that from Långhyttan, showed the effect of this reduction during the boil[42]. H. H. Campbell, however, took issue with Åkerman on this point, and, by a system of calculation by which he estimated the total weight of the slag at different times during the blow, showed that, while the slag would oxidize carbon and lose some of its iron in the process, the loss by weight of iron was not as great as Åkerman had argued[42, 66]. He admits, however, that oxidation of impurities by the slag is possible, and even a regular part of the open-hearth process[42, 66]. The present writer adds to the analyses quoted by Åkerman, others quoted in Table IV. to show how general is the practice of iron being saved by reduction from the slag.

In this connection, the following test carried out by the writer at a large American Bessemer works tends to show that the slag not only oxidizes carbon, but silicon as well, and materially hastens the operation. It is the custom at these works to hold back all the slag possible after each blow, until, at intervals, the vessel is drained clean and a fresh start taken. For several hundreds of heats a record was kept of those where the slag was dumped out clean, and those where it was retained. The average time of blow of the heats which started with some slag in the vessel was 12 min., while the average time of those which had no slag at the start was 16 min., an increase of 33⅓ per cent. In every respect, except the presence of slag at the start, the consecutive heats were approximately the same, or as nearly so as circumstances would permit.

small converter modifications in France[31], so that a study of small converters there represents to some extent a study of the Robert modification there. Mons. A. Tissot says that small converters have come into general use in France for steel-castings, and seem to satisfy many requirements. They produce steel at high temperature, making complicated castings of excellent quality, thus creating a new industry and greatly aiding in extending the use of steel-castings. He states that the output may be varied widely, and that the metal is milder than open-hearth steel, and has great elasticity and power of resisting shocks. With the aid of a molding-machine, two men can make from 1,300 to 2,400 lb. of complicated castings, weighing from 10 to 40 lb. each, daily[55].

Such statistics of the matter as we have are as follows: In 1888, there were 4 small converters in France, which produced 5,100 metric tons of steel-castings; in 1898, there were 8 special converters in France, which produced only 6,200 metric tons of steel-castings (or 32.1 per cent. of all steel-castings made), while 3,100 metric tons (16.1 per cent. of all) were made in regular Bessemer converters and 10,000 metric tons (51.8 per cent. of all) were made in open-hearth furnaces[56]. Thus, ten years has made little increase in the actual tonnage of steel-castings from small converters in France, and has made a considerable reduction in the output of each converter, showing that they were, probably, not as continuously occupied as they were ten years ago.

The Robert Modification in America.—Up to July, 1890, 14 Robert-Bessemer converters had been installed in the United States, ranging from 1.5 tons capacity each to 5-tons capacity each[52]. In 1894, only six of these were still working; in 1896, the number had been reduced to 5, and, in 1898, to 2. The latter are still running at the works of "The Detroit Steel & Spring Works," in Detroit. They are of 2-tons capacity each, and the output of the plant is 8,000 tons annually, mainly steel-castings from 2 to 3 lb. weight up, and also spring-steel and springs of all kinds[67].

The Tropenas Converter.

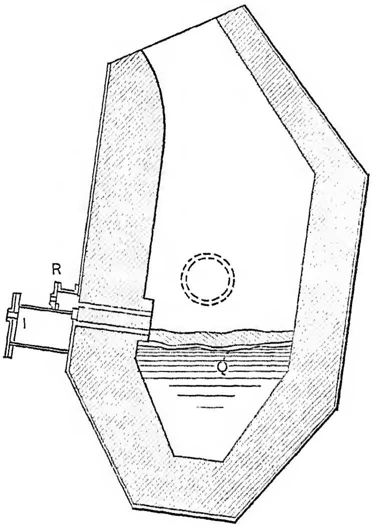
About 1889, the firm of Bergés, in Paris, erected a Robert-Bessemer foundry-plant under the direction of their engineer,

M. Alexandre Tropenas. They later gave the matter up, on account of the great waste of metal in the operation, and the Robert Society took it up. M. Tropenas, however, went shortly afterwards to Sheffield, England[50], where he experimented further with the Robert modification without success, and then took out a patent on some modifications of his own, which he called the "Tropenas Process" (English patent, No. 7,625, May 2, 1891). In 1891–2, Edgar Allen & Co., of Sheffield, put in a Tropenas-Bessemer converter of 800-lb. capacity, which was so satisfactory for steel-castings that they built a foundry-plant of three 2-ton vessels[57, 20], and secured the exclusive rights to the patents in England. The product of this plant has been used almost entirely for castings, for which the modification has certain admitted advantages over open-hearth and regular Bessemer metal. With more discernment than some others had shown, M. Tropenas emphasized these advantages, without trying also to place the converter where it would show to least advantage,—in the production of ingots and large tonnages in competition with its larger rivals. For steel-casting work it has thus extended widely (as shown by Table XIV.) and with fair rapidity, in view of its restricted field and the disadvantages it had to overcome at first, with the memory of the more or less complete failure of its predecessors still fresh in mind. In America it is young yet, but bids fair to make a place for itself in the foundries and to keep it, especially with the growing demand for small castings, and with the insistence that genuine steel-castings shall be furnished when steel-castings are contracted for in the smaller sizes of patterns.

The Tropenas Converter.—Drawings of the converter are shown in Figs. 14 to 17, which, with the following description, are taken from the patent specifications[19]. The first thing that one notices is the two wind-boxes and sets of tuyeres. There is a separate connection from each wind-box to the source of wind-supply in the hollow trunnion. A valve regulates the supply of blast to the upper wind-box. The object of all these arrangements is explained later. The vessel tilts on trunnions, and the shell is circular in horizontal section. The tuyeres are horizontal when the converter is vertical and are placed in the back, which is not quite a plane, as in the Robert modification, but approaches such a form by having a larger

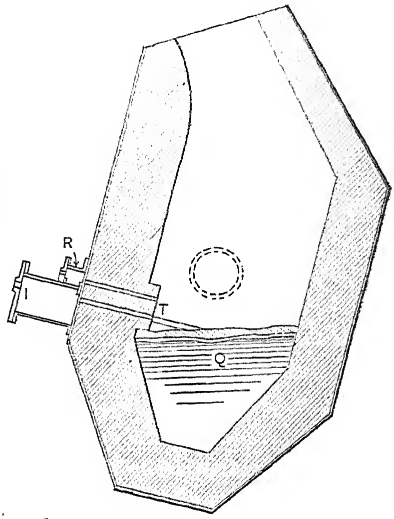
radius inside than the remainder of the lining. Both sets of tuyeres are arranged so that the orifices are always above the

FIG. 14.



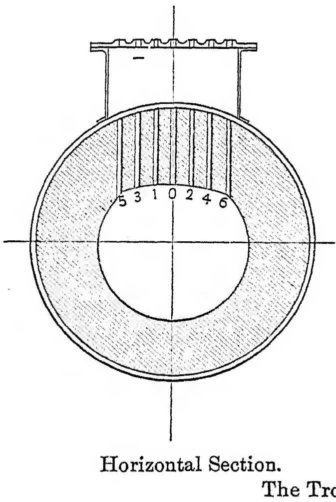
Vertical Section.

FIG. 16.



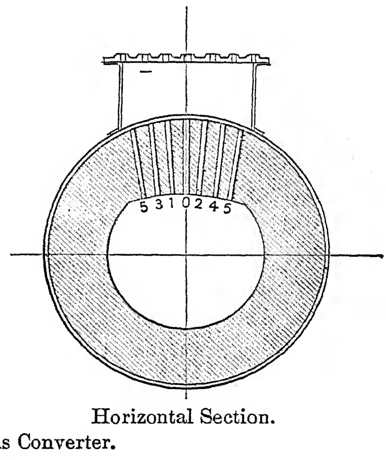
Vertical Section.

FIG. 15.



Horizontal Section.

FIG. 17.



Horizontal Section.

The Tropenas Converter.

level of the bath. This necessitates tipping the vessel slightly forward, in order to make the tuyeres point downward and

cause the blast to impinge on the metal, and the circular form of the inside of the back lining brings the two outer tuyeres nearer the bath than the remainder. The object of this is the following: It is supposed that, if the vessel is tipped wrongly, so that any of the tuyeres are in danger of being obstructed by the slag, the two outer tuyeres will be first obstructed and will give warning, so that the angle of the vessel may be corrected before the other tuyeres become obstructed. To facilitate observations on this point the patent specifications call for a cover to the lower wind-box with glass sight-holes therein, but this is not used in actual practice. The difficulties connected with using it, and the danger of the glass being broken mechanically, or by radiated heat when the wind is shut off, is too great.

The sets of tuyeres project inside the rest of the lining to form a sort of a shelf, with the object of lessening the rotation or movement of the bath, or agitation during boiling. To prevent horizontal rotation, each set of tuyeres is symmetrical with respect to the central tuyere. The two sets of tuyeres are parallel, and the individual tuyeres in each set may be parallel to each other, or fan-shaped inwards or outwards.

To obtain maximum depth with maximum surface, and thus further prevent horizontal rotation, the bath in 1-ton vessels is in the form of a truncated cone (see Figs. 14 and 16); in the larger vessels it has the same section throughout its depth. Relining and repairs to the lining are performed through a door in the side of the shell. The converter is tipped either by hand, through a worm and gear, or by power. An index on the fixed support, in connection with a pointer on the trunnion, shows when the vessel is vertical or what its position is.

As the main object of the Robert modification was to cause maximum rotation, so the main object of the Tropenas is to prevent any rotation at all. Oxidation of impurities is supposed to take place by the blast from the lower tuyeres, or "tuyeres of reaction," on the very surface of the bath, whence it proceeds downward from molecule to molecule to the very bottom, without any movement or current of metal. M. Tropenas says: "It may here be observed that the most impure steel manufactured by the pneumatic process is that produced from a bath which has received the largest amount of gyrating, churning or stirring in

its molten state." The upper tuyeres, or "tuyeres of combustion," are for the purpose of burning the carbon monoxide and hydrogen given off by the bath. They are generally oval or rectangular, with their large axis horizontal. The valve leading to them is not opened until the carbon begins to burn. The patent specifications also cover the use of a regenerator, but this has been given up. The lining is thicker on the tuyere side, on account of the greater wear at that point.

Analyzing some of the above modifications, we find:—

The curved form of the back lining is novel, but it is difficult to see what advantage it confers over the flat back of the Robert modification, unless we are told how the outer tuyeres give warning when they become obstructed. For a matter of fact, if any such thing is suspected, it is best to stop blowing and clear all the tuyeres before proceeding farther.

The shelf formed by the tuyeres is also novel, but actually it breaks off after the first blow or so, by the expansion and contraction of the bricks, and is a negligible quantity in discussing the modification. Even if it remained, its function is valueless, as will be shown later. The same may be said of the truncated cone-formation of the bath.

The symmetrical arrangement of the tuyeres is different from Robert's modification, but otherwise is not new. As far back as March 15, 1856 (English patent No. 630), Bessemer patented blowing on the surface of the bath through parallel tuyeres situated above it, and on only one side of the converter. A drawing of the proposed vessel is shown, and the point is very clear. The tuyeres of the Thomas modification also were parallel.

Among the many observations which occur in regard to the elaborate arrangements for preventing any "gyrating, churning or stirring," the following only will be discussed here: In the first place, churning, stirring, violent and explosive boiling and motion of the bath is going on during the whole time that carbon is burning in this converter, just as in every converter, and if M. Tropenas succeeded in preventing it, he would merely prevent the operation from taking place at all.* Even the open-

* Suppose M. Tropenas should succeed in his designs, what would we have? Chemical action downwards from molecule to molecule would have to be almost instantaneous to prevent enormous waste of iron from oxidation in the upper

hearth charge boils violently of necessity. When the Tropenas-Bessemer converter spits, as it does under certain conditions to be mentioned later, it spits almost pure iron oxide, as I have learned by analysis, and this shows that the iron itself is in motion, which may be confirmed by any one looking into the mouth of the converter at any time. The modifications under discussion may prevent the rotation which causes the heavy wear of the lining in the Robert converter, but cannot prevent the natural motion of all converters. In making these claims, M. Tropenas has followed in the footsteps of his predecessors, but those steps pointed in the wrong direction. In order to escape the illogical reasoning of chemical action downwards, some have claimed that the bath is without motion, but that the impurities float up to the surface through gravity and thus become oxidized[60]. It is hardly worth while to argue against reasoning of this unsubstantiated variety. If the Tropenas advocates wish to establish claims of advantages for their steel, let us see the superior metal, and then we can credit reasoning to explain the fact. It can be shown that Tropenas steel is not any purer than any other steel (see page 881).

The only practical novelty of the Tropenas modification is the upper row of tuyeres, and this is a novelty of special arrangement only, for we have already seen that the idea is old (see pages 852 and 858). At first sight, this arrangement seems to be a great advantage as a means of securing hot metal for small castings, but, on further thought, doubts arise: First, how do we know that just enough air is introduced through the upper tuyeres to burn the carbon monoxide and hydrogen generated and leave no excess? An excess, if present, would not only represent a loss of blowing-power, but also consume the heat necessary to raise it to the temperature of the other gases.* M. Tropenas says[58] that the free section of the upper tuyeres is 75 per cent. of that of the lower tuyeres, but does not tell us how this figure was arrived at, or why. Is it supposed that

layers, before the impurities in the lower layers were reached at all; the beneficial saving of iron from reduction of the slag by carbon (see page 866) would be lost; oxidation by means of the slag would be absent, except on the very upper surface, and the operation would be much longer than it is, and corrosion of the lining by oxidized iron would be large.

* I believe that Mons A. Abraham[62] was the first open skeptic on this point, though it has, undoubtedly, occurred to others also.

the blast from the lower tuyeres burns the carbon to carbon monoxide and the upper blast completes combustion? and have these things been proven by analysis? Again, why are the upper tuyeres from 4 to 7 in. above the lower tuyeres[58]? Why not nearer? and, carrying this question to a logical end, why not join the two in one set of tuyeres elongated vertically? One would think this would be an advantage, since combustion would thus be completed at the nearest possible point to where the heat is wanted.

To clear up these points, if possible, I have carried on a series of experiments, to which attention is merely directed here, as they will be described later.

There are 7 tuyeres in each set. The diameter of the lower ones is from 1.25 to 2 in., according to the size of the converter. In the 2-ton converters it is about 1.5 in. Tuyeres last from 30 to 40 blows[60, 58, 20], or more, but it is economical to change, or, at least, patch them, about twice as often as this, as the spitting of the converter is very bad if the tuyeres are so short as not to deliver the blast in well-directed, independent streams. With constant patching they may be made to last as high as 175 blows. Linings may be made to last as high as this also, but usually average from 125 to 150 blows[58].

For the blast, any blowing-engine which will give, at 4.5 lb. pressure, 880 cu. ft. of air per min. per ton of charge will serve[58, 61]; and, in this country, blowers of the 2-impeller type, costing only a few hundred dollars, are used with entire success and without any reserve-blower required. Such a one, for a 2-ton converter, takes about 65 H.P.[61].

The Operation.—The pig-iron most suitable for this modification is stated to be that having an analysis within the following limits:

Silicon,	from	2.50	to 3.50	per cent.
Manganese,	"	0.50	" 1.25	"
Carbon,	"	3.00	" 4.50	"
Sulphur,	"	0.03	" 0.06	"
Phosphorus,	"	0.04	" 0.07	"

In the cupola the silicon would probably be reduced by about 0.35 per cent., and the sulphur would be increased 0.02 to 0.035 per cent., depending on the coke used. With the iron is mixed from 20 to 30 per cent. of steel-scrap, which further

lowers the silicon. It is claimed that, on account of the high temperature of the operation, more scrap can be used than in any other process[59], and as high as 40 per cent. may be charged[57]. However, it is not clear why this is called a characteristic of this operation; any cupola can melt 40 per cent. of scrap or more, if called upon to do so, but it is never an economical thing to do, as it takes an undue amount of fuel to melt such a charge, and this result would be the same, no matter what the temperature of the following operation. The iron must come to the Tropenas-Bessemer converter physically hotter than is required for the larger, regular Bessemer converter, and, for the latter practice, 25 per cent. of steel-scrap is the maximum economical proportion under ordinary conditions.

During the first period of the blow, which is, roughly, from 25 to 30 per cent. of the whole in point of time, the valve to the upper wind-box is closed, and the lower blast does all the oxidizing. The pressure is about 4 or 4.5 lb. per sq. in. The converter is inclined forward, as shown in Fig. 16. The charge is calculated so that the relative positions of tuyeres and bath shall be about as indicated,—that is, the blast shall strike the metal about half-way across.* This period lasts until the carbon begins to burn, there being, meanwhile, many sparks given off, but no flame.

At the beginning of the second period, a small tongue of cherry-colored flame appears at the mouth, accompanied by some red smoke. It elongates and becomes whiter and strong, when the converter is turned back into the position shown in Fig. 14. In no case may the tuyeres come into a horizontal position, or come below the surface of the bath.

The red smoke gradually ceases. The blast-pressure is re-

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* That the converter shall have exactly the angle shown is a very important matter, and influences largely the spitting and, therefore, the waste of iron. As the lining wears away the charge must be carefully regulated so as to preserve these relative positions. The position of the bath is determined by opening the back of the wind-box and looking through the tuyeres before every blow, while the position of the vessel in relation to the horizontal is shown by the index and pointer already mentioned. If the converter is tipped too far forward, the spitting may be excessive during the whole blow, and even large masses of metal may slop out of the mouth at the most violent period, which is just previous to the first drop of the flame.

duced to 3 or 3.25 lb. The tuyeres are now in contact with, and below the top level of, the slag, and it is stated[19] that the slag freezes on to the end of them to form projecting tubes which protect their ends and also aid to keep the bath without motion. The valve to the upper tuyeres is now opened part-way to burn the hydrogen and carbon monoxide that is beginning to be given off by the bath. The pressure is again reduced very slightly[61]. The flame becomes very intense, violent and large. The upper valve is then opened full. If the tuyeres have been worn down short, or if the position of the vessel is not just right, there will be much spitting, or even slopping, out of the mouth at this time. Finally, the flame flickers and shortens, and red smoke again appears. After a further space of about 1 min. the flame takes a distinct drop, but remains white, showing its content of carbon monoxide. If the spitting is bad, it is usually at its worst immediately preceding this drop, which is considered to mark the end of the second period of the blow. In point of time this period represents roughly from 33 to 50 per cent. of the whole blow.

The third period covers the remainder of the blow and is distinguished by a fluctuating flame, which may rise and fall at intervals. During the whole time, dense volumes of red smoke are given off, but there is never much spitting, unless the position of the vessel, the wear of the tuyeres, or both, are very bad indeed.

Finally, the flame becomes larger and more intense than at any time before, and then drops, and the vessel is turned down.

The total time of the operation is from 15 to 22 min.[58, 61, 63]. Between successive operations, however, several minutes are consumed in pouring, and then preparing the bath for the next blow, by first skimming off from its surface the cupola-slag, or other foreign material, the converter being in a horizontal position, and afterwards taking off the back of the wind-box and tipping the converter towards the vertical position until the tuyeres have the proper relative position with the bath. If the proper amount of iron was poured in, the converter will then have the position of Fig. 16.

Ferrosilicon and ferromanganese for recarburizing are added either in the vessel or in the ladle, and, usually, after being

melted in a crucible furnace, or a small cupola[58], but may be added simply red-hot.

Loss.—The loss of iron in the process has been the subject of much controversy. M. Tropenas says, that an average of a great number of operations of regular running shows from 5 to 6.5 per cent. of cupola-loss and from 10 to 12.5 per cent. of converter loss, or about 17 per cent. average for the total[58]. At the Edgar Allen plant, however, it is said to be only 14 per cent. in all[60]. At the Sargent plant in Chicago, it is said to be "17 per cent. and up"[61]. By those who have also had experience with the process, it has been freely stated that the loss is often double the above figures for months of regular running at a time, and that the spitting and the red smoke given off is larger than in the regular Bessemer converter, in proportion to the relative sizes of the charges. M. Tropenas admits the red smoke, but says that the iron so burnt does not exceed from 1 to 1.5 per cent. of the bath, as an average of several years' working, and claims that the spitting is less than in the regular Bessemer converter, and that this decrease makes up for the excess of red smoke[58].

Personally, I believe that this controversy arises on account of the great variation in the working of the converter, and the frequent lack of attention to the two points which have been mentioned,—namely, working when the tuyeres have become worn down short, and not preserving carefully the proper relative positions of tuyeres and bath. Again, then, let us say that the tuyeres must be sufficiently long to deliver well-directed, non-interfering streams of air, and these streams must impinge on the bath at angles to the surface of almost 180°. Otherwise the blast may produce a rhythmic, back-and-forth vibration of the charge, which causes very heavy spitting and, during the boil, much slopping from the mouth of the vessel, and it takes only very slight variations from the proper arrangement to cause bad results in this respect. I have known a certain plant to run continuously for months, with an average loss of over 30 per cent., and I have known the same plant to give 16 per cent. of total loss for an equal length of time, in consequence of a change in this regard.

The matter of loss is too important to be passed over without special attention. It is the great drawback of this modifi-

cation of the Bessemer process, and has caused many foundries to reject the process, which otherwise would have found it to be of immense advantage to them. The Tropenas people do not seem to have realized its importance. The figures which have been published are too indefinite, and there are not enough facts furnished with them.

In building the plants, too, the matter is not emphasized sufficiently. So far as I know, there is not a Tropenas-Bessemer plant in this country which is properly equipped with metal-scales, so that the metal may be regularly weighed after every operation. In building a regular Bessemer plant, what would be thought of the engineer who did not arrange so that metal not only may, but *must*, be weighed before going into the cupola, before going into the converter, and after it is made into steel? Yet this is just as important in a Tropenas plant. It is not enough to know the average loss for the month, or even for the day; the loss must be determined for every heat of every day, if we wish to improve and to know how to perpetuate the improvement. To the apparent indifference on this point, I attribute the variation and the frequent poor economic results known to have been obtained in the use of this method.

If the practice is followed of determining the final weight of steel made from the weight of castings shipped, there will be a loss of 1 or 2 per cent. or more, due to spattering in pouring. This has nothing to do with the steel process. It varies with the size of castings,—that is, the number per heat,—and is an item not appreciated except after actual experience.

The alleged advantages of the Tropenas-Bessemer process over the open-hearth process for steel-casting work are based on five claims:

1. *That it is Cheaper to Install.*—This is admitted, since the first cost of an open-hearth furnace is much more than that of a small converter-plant, but the admission is qualified in this way: On account of the length of time necessary to repair a converter with fixed bottom, and because these repairs are necessary every 20 heats on the average, due to the high temperature of the operation, three vessels must be installed to keep one working continuously, for, at any one time, one converter is working, one is repairing and the third drying.

A plant of three 2-ton converters would thus replace one open-hearth furnace of from 50 to 70 tons daily capacity.

The small converter is relatively cheaper to install than the large converter, because of cheaper blowing-mechanism. Any blower of the two-impeller type capable of giving the necessary wind may be used without hesitation or reserve.

2. *That the converter-plant may be shut down and started up at short notice and at slight additional expense, and that it may lie idle without tying up much capital, and thus has great elasticity of product.*—This claim also is admitted, since an open-hearth furnace must be run continuously to be at all economical, while the chief additional expense of running the converter intermittently is the small amount of fuel to heat up the apparatus before the first blow. This advantage, however, applies only to the following limited classes of manufacturers:

(*a*) Those who have ample room and prefer to do all their work in daylight.

(*b*) Some iron and malleable-iron founders, who are frequently called upon to furnish steel-castings to good customers, but do not have a large regular or steady demand. Under these circumstances they are wont to sublet such contracts to steel-foundries, with the result of divided profits and occasional serious delays in delivery or defective castings furnished, for which they are accountable, but not directly responsible.

(*c*) Manufacturers who need a few thousand tons of steel-castings per year to put into the product of their own factory, but whose requirements are not large enough to warrant running continuously an open-hearth furnace of economical size. In the United States there are several concerns of this class which have put in Tropenas-Bessemer plants.

(*d*) Open-hearth foundries which have occasional desirable orders for castings not suitable to open-hearth steel, on account of being small, or with thin sections, or with special chemical requirements. Thus, a good customer may desire small-bevel gears in large quantities, with high carbon to give good wear, or a locomotive-works will often send out orders for several large castings, together with a number of small ones. To get the desirable work, the foundry may take the order, and sublet the small work to another foundry at an actual loss to itself,

relying on the larger work to make this up and also furnish profit for both parts.

(*e*) Also, in general, any foundry which expects fluctuating orders.

3. *That it is better to have a small amount of metal coming to the foundry at frequent intervals than a large amount at long intervals.*

(*a*) Because of greater possible variation in chemical composition and consequent elasticity in fulfilling different physical requirements. Each unit of steel must be uniform in chemical composition, and, with large units, it is difficult to fit them exactly to the size of the different orders. It is impossible to divide units into smaller units unless the steel is extremely hot, since it loses too much heat by radiation on standing or during repouring.

This is an advantage of constantly-increasing importance with the more extended use of steel-castings in many industries. Alloy-steel castings, hard steel for wearing purposes, soft steel to stand shock or to give high magnetic permeability,* etc., are often asked for, perhaps all on the same order.†

(*b*) Because of the better arrangement of the work, since the pouring may be done by one gang who do nothing else and become very expert at it with practice, while the rest of the shop is not interrupted at all in its regular work. When the pouring is done in large units it takes a number of men to do it, and the whole shop is more or less interrupted for twenty or thirty minutes, three or more times a day, depending on whether the foundry is served by one or more furnaces. The amount of time lost in this way must be weighed against the wages of the extra men needed for continuous pouring, and each shop must strike its own balance.

Again, the crane, or other apparatus for pouring, must be more powerful when pouring in large units. When pouring in small units, and continuously, this apparatus is never avail-

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* Especially for certain parts of motors.

† Especially is this true in the matter of small bevel-gears, etc., which many manufacturers now prefer to have made from so-called "semi-steel," "McHaffie steel," and other "steels," which are not really steel at all[15], because crucible steel is too expensive, while the open-hearth foundries cannot furnish metal with the required properties of wear, etc.

able for anything but pouring, and an extra one must, therefore, be kept for the purpose.*

(*c*) Because of the smaller floor-space required for setting molds. The work of molding, setting, pouring and "knocking out" can go on, continuously, in a smaller space; and this is a valuable economy in the foundry.

The three above counts are not so definite but that there may still exist a difference of opinion in regard to this claim. When the average size of castings is large, large units must, of course, be used. The usual size of the Tropenas modification is from 1 to 2 tons. Occasionally, large castings may be made by combining two or more heats, the metal being so hot that it may be held in the ladle while more steel is being made, without forming much skull;† but it would not be good practice to do this as a regular thing; and an open-hearth furnace of suitable size would, undoubtedly, be preferable.

4. *That the metal is of better quality:*

(*a*) On account of freedom from blow-holes and gas-cavities. That sponginess and blow-holes are always absent is not true, but that the metal is comparatively very free from these defects must be admitted. It is my experience that, with ordinary care in two particulars, we can be as sure that castings made with this converter will be entirely sound, as we can be of anything siderurgical. The two particulars are: To see that the blown metal is dosed according to orders, and to see that sufficient time is allowed for the complete spiegel-reaction to take place before the castings are poured. The latter point may be determined by the appearance of the blown metal. If

* As Tropenas-Bessemer metal is so hot and fluid that it is customarily poured over the lip of the ladle, an inexpensive and apt substitute for the traveling-crane for pouring is a traveling ladle-carriage on a convenient track; but, so far as I am informed, it has never been thoroughly tried in a Tropenas foundry in this country.

† The American representatives of M. Tropenas claim that a 3-ton casting may thus be made with a 1-ton converter with less than 2 lb. of ladle-skull[59], and, from the large castings which I have made with a 2-ton Tropenas-Bessemer converter, I am inclined to believe this, except in regard to the weight of skull. It is thought that 200 lb. would be a more reasonable claim to make in this connection.

Edgar Allen & Co. made some 6-ton castings with two 2-ton converters, making the five necessary blows in an average time of 1 hour and 55 min. The weight of ladle-skull is not stated[57].

the exposed surface shows the least "wildness," the castings should not be poured until no "skippers" appear, even when a cold, dry rod or skimmer is immersed for an inch or two into the molten metal. When the metal has been blown too full, it may require an extra addition of aluminum before the proper quietness is attained.

M. Tropenas claims that blow-holes are due to the decomposition of the moisture in the air which is blown through the metal in some other modifications of the Bessemer converter, and, as no air penetrates metal in his modification, it can contain no blow-holes [19, 20, 57, 58, 59], and that what gas it does contain will escape very easily when the metal is poured, on account of the fluidity of the steel[58]. It is my present belief that this latter point is the sole cause of the freedom from blow-holes, and that the fact that no air penetrates the bath has nothing to do with it. No air penetrates metal in the open-hearth process, yet castings made of this metal are the most liable to blow-holes. Without entering here into a lengthy discussion of the matter, since M. Tropenas has offered no evidence in support of his claim, the reader is referred to the very excellent treatise by Caspersson and Åkerman[73], which shows clearly the intimate relation between the location or the absence of blow-holes, and the temperature of the steel when poured.

(*b*) On account of greater softness, due to smaller proportion of impurities. By "impurities," M. Tropenas, undoubtedly, means carbon and silicon, since it is not claimed that sulphur and phosphorus are eliminated. If oxygen, hydrogen or nitrogen had been meant, probably some evidence would have been offered in support of such a claim, but this has not been done. In any case, the truth of the contention has not been established, and the claim is not admitted.

With the results of the Clapp-Griffiths experiment still fresh in mind, the time is not opportune for a repetition of such claims unless strongly backed, and the present ones have practically not been backed at all by evidence. M. Tropenas asserts that the blown-metal contains from 99.75 to 99.80 per cent. of iron[19, 58], but a glance at Table III. shows that this is not any better than regular Bessemer metal. M. Tropenas says[60], that the most impure steel is that which has undergone the

most churning in its molten state, and his modifications propose to avoid this churning as much as possible. The object seems to be to prevent metal and slag and metal and gas from mixing together, for the same reasons as given by M. Robert [58, 60], and the answers made to Robert would apply equally here.

It is claimed[60] that the lower silicon causes the steel to be more weldable and to give better elongation with the same tensile strength as open-hearth or regular Bessemer metal, but, as we do not admit the original claim, we cannot admit the corollary without independent proof. Some tests were published to this end and are here copied in Table XV., while some tests of open-hearth steel-castings are given for comparison in Table XVI. The latter were chosen entirely at random from about 1,000 results of tests, which were kindly furnished to me by Benjamin Atha & Co., of Newark, N. J., and may be said to represent fairly their average results.* If the Tropenas tests were chosen in a similar manner, they have the best of the argument, but it is not stated that they were so chosen, and they have the appearance of "picked results," it must be admitted. If picked results had been taken for the open-hearth table, the showing could have been easily made superior to the Tropenas table. However, on any basis, the Tropenas showing is very good and proves that excellent steel-castings can be made with this converter.

Table XVII. shows tests of another lot of open-hearth steel-castings which were not selected tests, but were made by Capt. D. A. Lyle, U. S. A., on some castings made by the American Steel-Casting Company to fill a certain order. They are, therefore, fairly representative[65].

Table XVIII. shows the tests of some crucible-steel castings.

It is stated that Tropenas-Bessemer castings of from 0.25 to 0.30 per cent. carbon are easily weldable[60], but this is no different from open-hearth castings of like analysis.

It is said also that the castings need only a very little annealing or reheating[59], but this is a matter which depends almost

* The variations seen are intentional to fill differing requirements, and are not due to irregularities in the process.

entirely on circumstances and the customer, and is not probably related to the quality of the metal under discussion.

It is claimed again that steel may be made with very small amounts of carbon, manganese and silicon, and, therefore, have high magnetic permeability, and are especially adapted to dynamo-castings and other electrical work[64, 20]. This claim appears to be substantiated, to some extent at least.

5. *That the steel is extremely hot and fluid.*—This is admitted even by the severest critics of the process. In fact, the steel is so hot as to make it entirely suitable for castings which could not be made from open-hearth metal at all, except at prohibitive cost for roof and lining. It lies in the ladle white and dead, and pours in a stream which breaks off sharply and quickly,—somewhat like mercury, or water when poured over a thin lip. It fills very small molds accurately and sharply, and runs into even quarter-inch sections of relatively large area. Castings, down to a few ounces in weight, may be made regularly as a part of each day's work, if desired, and ladle-skulls are always small. All the indications are that the metal is hot enough for all reasonable foundry-requirements. Adams says its temperature is about 1700°C.[61], but this seems a little vague; and it is regrettable that those engineers who have had the opportunity have not made more accurate determinations.

Of course, this metal will not remain molten while running in a small mold as long as cast-iron will do, but this is a matter due less to the temperature of the metal itself than to the difference between the melting-point of the metal and the temperature of mold, in which respect the iron always has some hundreds of degrees the advantage.

It is well known, of course, that the open-hearth furnace can be made very hot indeed,—that too high a heat must, in fact, be constantly guarded against,—but this in no wise affects what has been said above; for "hot" is a comparative term, and what would be much too hot for ingots would be altogether too cold for small castings. On the other hand, if the open-hearth melter should try to run hot enough to pour the whole of his smallest economical charge (say, 15 or 20 tons) into small castings of from 20 lb. down to 0.25 lb., he would probably ruin his roof.

It was similarly pointed out long ago that the regular Besse-

mer process might produce, and must guard against, too hot a metal; but the same comparison applies here also. However, while the open-hearth furnace can be made to produce metal hot enough for almost anything, provided expense is no object, the Bessemer converter, blown in the regular way, could never reach a temperature high enough to pour its whole product regularly into small castings.

Both the open-hearth and the Bessemer processes can make small castings with the first part of the charge, if desired; but it takes so long to pour a number of small castings that, when the latter part of the charge is reached, the metal is too cold in each case to run in small molds; and the skull formed is so heavy that the expense of the process is increased appreciably.

Long Tuyere Modification.

About the year 1901, I was asked to build a plant for the manufacture of small steel-castings, in connection with an open-hearth foundry-plant of some years' standing. The molds for the small castings were to be made with a machine. In view of the history outlined in these pages, and some personal experience with the Tropenas converter, this seems to be the best available design; but its glaring defect, the fixed bottom, which causes so high an expense for repairs, and necessitates installing three converters in order that one may be in use all the time, was a disadvantage which the Tropenas representatives did not seem willing to rectify. Moreover, the stack of the Tropenas form is thought to be too short, in view of the excessive spitting which sometimes occurs, and the upper tuyeres are known to cause a loss of iron and of blowing-power. Whether they confer advantages in higher temperature great enough to offset this was doubtful.* I was permitted by M. Tropenas's representatives to visit one of the most complete Tropenas plants in this country, but did not learn as much in favor of the modification there as he had hoped I would. The idea of using it was therefore abandoned.

* While making castings averaging less than 20 lb. each, some Tropenas heats were blown without using the upper tuyeres. The resulting steel was amply hot for any purpose, and, apparently, just as much so as when the upper tuyeres were used. I have been told that the same thing has been done elsewhere, with the same result. A probable reason for this fact will be given later in this paper.

Several other modifications not unlike the Tropenas have been patented in this country, and one of these was seen during the investigation of the problem, which was best for the purpose in view. This had been operated for several months; none of the others had been operated at all. All are based on ideas or principles patented by Bessemer more than 30 years before,* and all appear to be, either a return to bad principles which had been abandoned elsewhere, or else they were too impracticable in design to command attention.

A type of converter was finally determined upon, which would give conditions more oxidizing and less irregular than those of Robert, but not so oxidizing as those of Tropenas. Thus, the tuyeres were neither below nor above the level of the bath, but on the same level, parallel and pointing downward very slightly.† Drawings of the converter, which was erected at the works of Benjamin Atha & Co., of Newark, N. J., and first operated in October, 1901, are shown in Figs. 18 to 20. Since then, two more like it have been added to the plant. All are of 2-tons capacity each. The bottom is removable, and the vessel is rotated by means of a rack and pinion in the usual way. To reduce the spitting, the stack is made very high, and, for still greater saving in the matter of loss, the lining on the tuyere side is very thick, thus allowing the tuyeres to be extra long. The tuyeres are placed in the back, which is flat. For tuyeres I prefer six 2-in. pipes rammed in the refractory lining, with the outer ends projecting 6 in. into the wind-box, to increase their length further. Two-inch wooden plugs also have been used, and withdrawn after the lining has been rammed around them, and 1.5 in. tuyeres also have been used with success. For the first vessel one extra bottom only was supplied. After what has been said above, it is needless to add that the plant is equipped with such metal scales that, for every heat, the weights are taken of cold pig-iron, melted pig-iron and steel in the ladle.

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* In fact, I have not read, in patent specifications or elsewhere, a single valuable manner of blowing iron which was not patented by Bessemer in the fifties. Bessemer himself called attention to the fact that royalties were being paid on "patents" which he had anticipated years before, and said that the public was now freely welcome to much for which it paid a high price.

† There is no claim for novelty in this practice. It is indirectly covered in several of Bessemer's patents, and definitely covered in his patent, No. 630, of 1856.

FIG. 18.

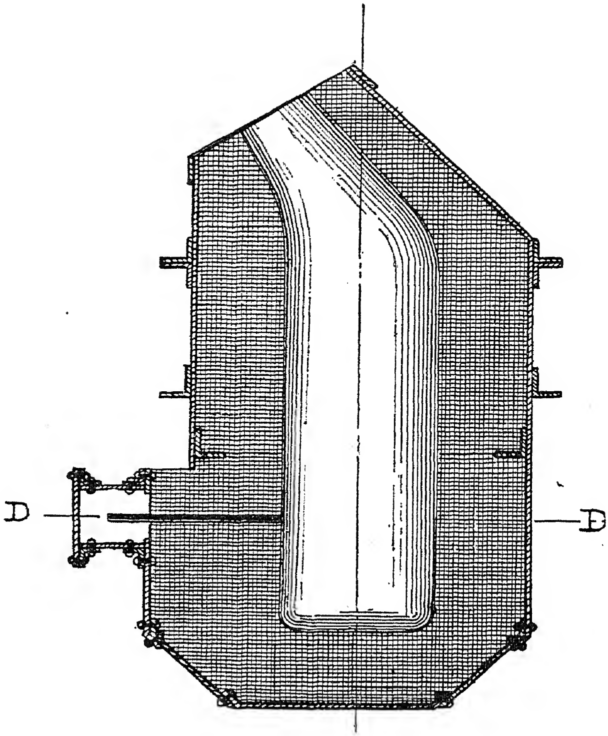
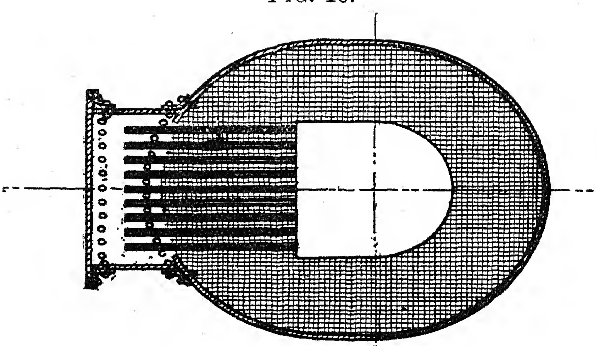


FIG. 19.

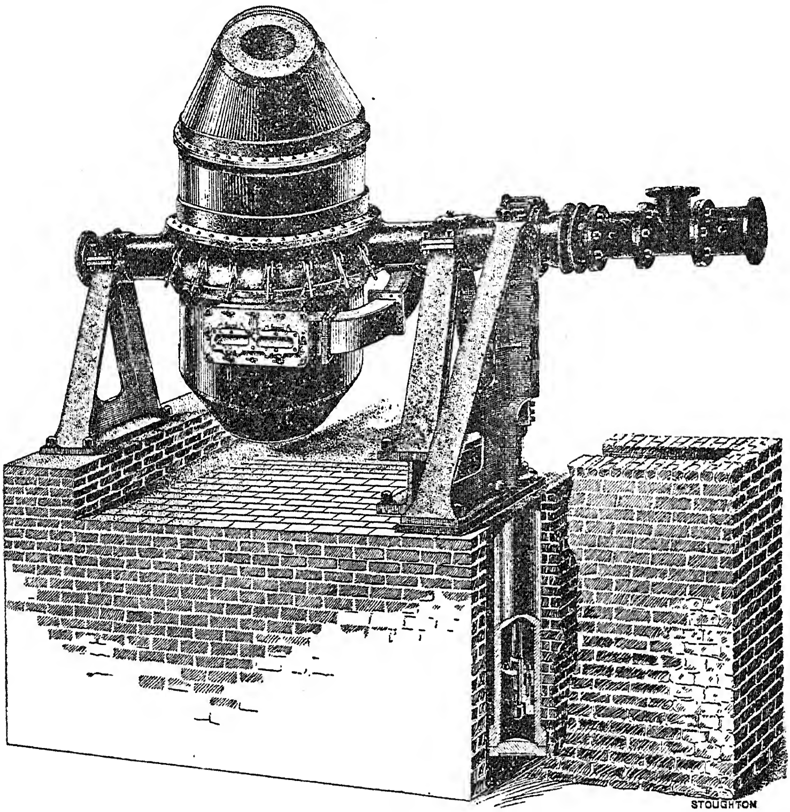


SECTION ON D-D-

The Long-Tuyere Converter.

When practice had shown that the converter worked as expected, and that the steel was amply hot for the purpose for which it was intended, it remained to study the conditions inside it to determine just how oxidizing or reducing they were. It is clear that, if oxidizing, there will be a waste of blowing-

Fig. 20.



The Long-Tuyere Converter.

power, of iron, and of heat; if not sufficiently oxidizing,—that is, if the carbon is not all burned to CO_2,—then we are not getting all the heat we might.*

The simplest and most definite way to determine this is by examination of the escaping gases, which was accordingly done.

* The ideal condition, of course, is when all the carbon is burned to CO_2 and there is no free oxygen left.

They were taken off through a 2-in. pipe, extending from 24 to 12 in. inside the vessel's mouth,* being forced out by their own pressure, and collected in the usual way, after being allowed to issue for at least 60 sec. before each sample was taken. The history of the blow was as follows, and the results of the analyses are shown in Table XIX:†

The pig-iron contained about 3.50 per cent. carbon; 2.15 silicon; 0.55 manganese; 0.05 phosphorus; and 0.035 sulphur.

The first sample was taken 1 min. after the carbon had begun to burn. As soon as the flame was white and strong, the converter was turned back the least possible amount, thus reducing slightly the angle of the tuyeres to the bath, and also lowering the level of their mouths. The blast-pressure was reduced from 4 to 3.5 lb. per sq. in. The red smoke then gradually decreased in volume, and, finally, ceased, the flame becoming larger and more intense.

The second sample was then taken. Very soon the flame began to shorten, and the red smoke appeared again.

The third sample was then taken. Finally, the flame dropped distinctly, but without disappearing.‡ Red smoke was still in evidence.

The fourth sample was then taken. The red smoke gradually disappeared as the flame became large. The flame became larger, more violent and whiter than at any time before, but was also freer from spitting, there being almost nothing projected from the mouth of the converter. This continued until the final drop.

The analyses show that, except for the last 5 min. of the blow (say, 30 per cent. of the time the carbon is burning), the gases are completely oxidized, and that even during this last period, 44 per cent. of the carbon is completely oxidized. Altogether, then, about 83 per cent. of the carbon is completely oxidized, so that, if we could introduce the exact amount of free air, and succeed in burning the carbon monoxide, we would gain about 10 per cent. of heat; but the air must be introduced directly to the surface of the bath, and at

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* *i.e.*, the pipe burned away somewhat during the test.

† Table XX. is also quoted for comparison.

‡ See footnote under Table XIX.

exactly the proper time, or the bath will not get the full benefit, and will be subjected to some unnecessary cooling-effect.*

The first deduction from the above facts was that the carbon burned so fast during the last few minutes that there was not enough oxygen supplied to oxidize it completely. But, on the other hand, the temperature of the gases is increasing all the time of the blow, and it is well known that, at very high heats, CO_2 dissociates almost as fast as it is formed. The action is progressive, and the exact relation between the temperature and degree of dissociation is doubtful; but the presence of iron and hydrogen materially increase it. Therefore, we had not yet enough facts to make accurate deductions[74, 75, 76, 77].

Obviously, the lack of oxygen at the end could be remedied by retaining the blast-pressure at 4 lb., instead of reducing it as stated. This was therefore tried, with the first result of reducing the time of blow from 21 to 14 min. The metal was hotter also; but whether this was due to the shortness of the blow or to higher oxidation of the gases than before could not then be told.

A gas sample was, therefore, taken at a period in the blow corresponding to sample No. 4 in Table XIX. It analyzed as follows: 10.5 per cent. of CO; 10.2 per cent. of CO_2; 7.4 per cent. of free oxygen. Now, there is about the same relation between the amounts of CO and CO_2 as before, although we have 7.4 per cent. of free oxygen present. Therefore, the incomplete oxidation of carbon towards the end of the blow is not due to lack of oxygen, but to the dissociation of CO_2 at that temperature, and no amount of extra air blown would remedy it, whether supplied by a second set of tuyeres, or otherwise.

The Process.—All grades of pig-iron from 1.25 to 3 per cent. of silicon have been used. The heat obtained, when using the first grade, is ample for all casting-work, but not quite so high as when we have more silicon, as one would expect,

* Another point is brought out by taking the analyses in connection with the foregoing notes of red smoke, due to iron oxide. This is shown by the calculations in the right-hand side of Table XIX., for the oxygen, which is not entering the gases, is mostly burning silicon and manganese in the first part of the blow, and iron in the latter part. The total amount of iron thus burnt is estimated at about 1.5 per cent.,—or one-half the sum of the manganese and silicon burnt.

for, though the extra high temperature is obtained from superoxidation of carbon, and not from oxidation of silicon, yet the latter aids somewhat. The conditions are not the same as in the regular Bessemer blow, where the carbon is not burned to CO_2 to such a large extent, and, therefore, the greater amount of heat comes from burning silicon. I prefer a pig-iron with not more than 1.6 per cent. of silicon before melting.

The iron is all cupola-melted, and the waste, including that of the cupola, is from 15 to 17 per cent., according to the iron used.

Bottoms last from 10 to 12 heats, and must then be patched somewhat. This may be repeated several times before the lining has to be renewed entirely. Relining of both bottom and vessel is accomplished very cheaply and quickly.

On account of the cheapness of starting up these small converters, almost all types of them are operated in daylight only. Up to the time of this writing (April, 1902), the machine-molding foundry, which is building to supply the converter which we are now considering with molds, is not completed, and the plant is limited in capacity to the molding-floor allotted to it. It thus makes from 20 to 30 tons each afternoon (from 1 to 6 P.M.), and uses the morning hours for patching, drying and heating. This product is equal to the total average, daily (10 hours), output of the largest Tropenas plant in this country, which contains three converters, each of them being the same size as the one we are now considering. This difference in product, per vessel per hour, is due mainly to the length of time taken to reline and dry the fixed-bottom converter, and the use of the extra bottom.

II. Modifications in the Operation, But Not in the Manner of Blowing the Charge.

When the charge is blown from bottom-tuyeres, similar to the method of the regular Bessemer converter, its small size renders special arrangements necessary, that there may be enough heat to carry out the process and leave the steel sufficiently fluid to be poured readily, and without excessive formation of skulls.

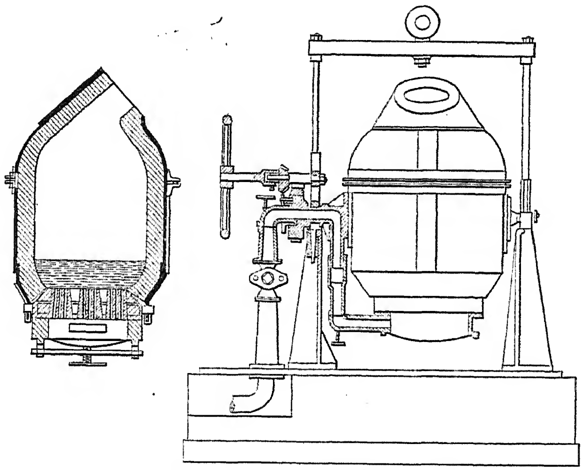
In discussing modifications along this line, no mention will be made of the process as carried out in Sweden, since, although

special conditions there have rendered special precautions necessary, and have given rise to several very ingenious improvements, they hardly amount to a modification of the process itself; and also because this subject has already been very ably and fully covered by others.

Davy's Portable Converter.

Davy's modified converter was designed to be carried to the molds and thus to dispense with a ladle in casting, and thereby save a large amount of heat. The blast entered through the bottom, as in the regular Bessemer process. The principal difficulties were said to be slag getting into the molds, and loss

Fig. 21.



Davy's Portable Converter.

of time in adjusting the mouth of the vessel, so as to pour into the proper place, especially with small molds. The modification was in use in England in 1886, and the waste was then said to be from 11 to 12 per cent., including cupola-loss, and the time of blow from 8 to 13 min. A drawing of the modification is shown in Fig. 21[5].

Hainsworth's Portable Converter.

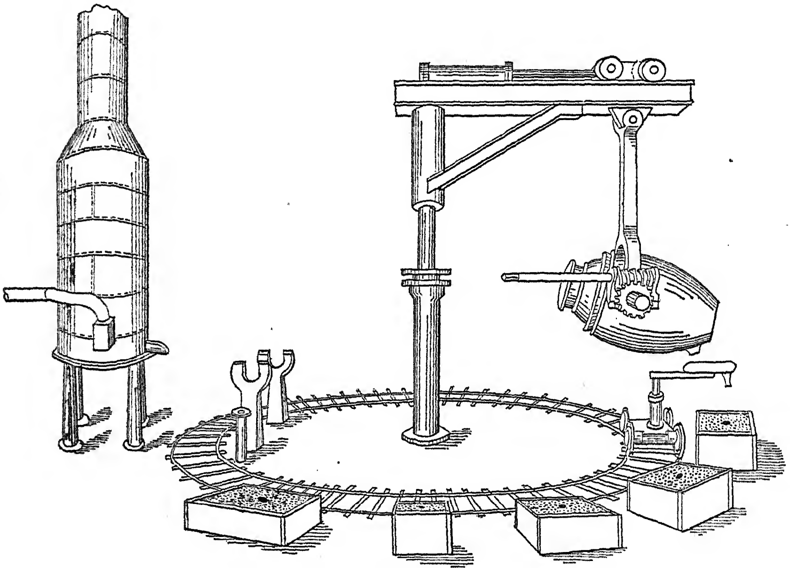
The principles involved in Hainsworth's improvement, patented in the United States on April 21 and December 23, 1884 (Patent No. 309,540), are substantially shown in Fig. 22. The details are briefly as follows:

1. The vessel must be small enough to be readily portable, the metal being teemed out of it without the use of a ladle.

2. For the better conservation of the heat, and to prevent the metal pouring out of the mouth, although allowing the escape of the gases, the mouth is partially closed by a circular plate, lined with fire-clay.

3. The steel is teemed through a nozzle, so as to get the metal free from slag. Before the iron is poured in for the blow, this nozzle is plugged with clay, which is broken out after the blow.

FIG. 22.



Hainsworth's Portable Converter.

4. The metal is not teemed directly into the molds, but through the medium of a trough, which may be readily adjusted, so as to deliver the stream at any desired point. The trough is supported near the mouth of the converter by some convenient means.

5. During teeming, the vessel may be raised and lowered by the crane, by the method shown in Fig. 22, or by hydraulic cylinder and plunger.

6. When the vessel is in that part of the foundry where it does the blowing, the blast-pipes may be readily connected and disconnected, or else they may remain connected all the time

by means of flexible pipes. In the latter case it is suggested that, should the charge become cool during teeming, some ferromanganese or spiegel may be added to it, to increase the content of carbon, and then this added carbon oxidized by turning up the vessel and blowing, in whatever location the vessel may be in, and the temperature of the charge thus raised.

In a second modification, patented at the same time (Patent No. 309,712), Mr. Hainsworth proposes to teem out of the vessel as before, but instead of carrying the vessel to the molds, to bring the molds to the vessel on a circular table, which may be revolved for the purpose, and also raised and lowered by means of a hydraulic cylinder and ram. This arrangement allows larger converters to be used, but requires an excessive amount of power for the table. Unfortunately, molds cannot be mounted on cars, as is common in ingot-casting plants, as the shaking in transportation would destroy the sand-mold.

The object of both these modifications is, of course, to get hotter steel in the molds by avoiding the use of a ladle and its cooling-effect. However, carrying a converter around a foundry is awkward at the best, and takes a large amount of power in relation to the amount of metal carried. Moreover, it is not clear that one could pour out of the nozzle shown, or any similar one, without getting slag into the molds.

The Walrand-Legénisel Method.

The Walrand-Legénisel improvement was invented by one of the inventors of the Walrand-Delattre, who now conceived the very ingenious scheme of blowing the iron in an ordinary Bessemer converter in the regular manner, through the bottom, and, after this blow, adding to the bath about 10 per cent. of ferrosilicon (containing 10 per cent. silicon), and then blowing again until this added silicon had been oxidized, giving its heat of combustion to the bath. High-silicon iron has been often used to obtain hot blows, and adding heat-producing materials at the end of a regular blow was suggested by Hainsworth; but M. Walrand seems, undoubtedly, to have been the first to increase the silicon at this stage of the process.

This type of Bessemer process was described in these *Transactions*[71], and has been discussed in several articles[68, 69, 70, 72]. It was tried in Chicago, but did not remain in use very long, and is not now in operation in this country.

TABLE I.—*Uniformity of Soft Steel in Percentage of Carbon.*

Name of Works.	Process.	Average Per Cent. of Carbon.	Maximum Deviation of Carbon from the Aver.	Average Deviation of Carbon from the Aver.	Weight of Heats, Tons.	Number of Heats Represented.	References and Remarks.
Pittsburg Steel Cast. Co.	Bessemer	0.0911	0.0189	0.0025	6 0	45	36 Consecutive heats over a period chosen at random.
Bellaire..................	"	0.081	0.011	0.0034	5.0	50	36 Consecutive heats over a period chosen at random.
Bethlehem..................	"	0.091	0.006	0.0036	7.25	15	6, 36 Raymond. (See Table III.)
Vulcan	"	0.073	0.027	0.0058	6.9	55	36 Consecutive heats over a period chosen at random.
"A." Clapp-Griffiths, *a*.	"	0 0878	0.0322	0.0129	2.1	37	36 ....
"A." " " *b*.	"	0.089	0.061	0.0142	2.1	38	36 . . ..
" " *a*.	"	0.09	0.050	0.0108	.. ..	154	36 .. ..
" " *c*..	"	0.103	0.457	0.0233	.. ..	163	36 .. ..
Chester................	Open-Hearth	0.151	0.069	0.0174	.	162	36 From analyses by Salom.
"C.".................	"	0.64	0.070	0.0165	..	20	36 A works of highest reputation.

a. Excluding all abnormal heats.

b. Including one abnormal heat.

c. Including nine abnormal heats; excluding one abnormal heat due to failure of blast.

TABLE II.—*Uniformity of Soft Steel in Percentage of Silicon.*

Name of Works.	Process.	Average Per Cent. of Silicon.	Maximum Deviation of Silicon from the Aver.	Average Deviation of Silicon from the Aver.	Number of Heats Represented.	References and Remarks.
Pittsburg Steel Cast. Co.	Bessemer	0.0167	0.0123	....	51	36 Consecutive determinations over a period chosen at random.
Bellaire.........	"	0.007192	0.0108	0.00276	26	36 Consecutive determinations over a period chosen at random.
Bethlehem....................	"	0.016	0.005	0.0019	15	6, 36 Raymond. (See Table III.)
Homestead....................	"	0.007	0.003	0.002125	8	29 Wood. (See Table III.)

TABLE III.—*Silicon in Mild Bessemer Steels.*

Heat No.	Analyses—Per Cent C.	Si.	Mn.	P.	S.	Steel Works.	Authority.	Remarks.
......	0.091	0.01	0.43	0.081	0.076	Riverside Iron Co.	30	Average of 61 blows.
......	0.091	0.012	0.401	0.088	0.06	" "	30	" 62 "
3286	0.07	0.004	......	......	......	Homestead.	29	E. F. Wood.
3300	0.08	0.01	......	......	......	"	29	"
3360	0.09	0.005	......	......	......	"	29	"
3363	0.08	0.006	......	......	......	"	29	"
3479	0.07	0.004	......	......	......	"	29	"
3487	0.07	0.009	......	......	......	"	29	"
3539	0.09	0.005	......	......	......	"	29	"
3540	0.08	0.008	......	......	......	"	29	"
......	0.08	0.007	......	......	......	"	29	Average of last 8.
2352	0.13	0.017	......	......	......	"	29	E. F. Wood.
2403	0.14	0.014	......	......	......	"	29	"
3286	......	0.004	......	......	......	"	29	Analyzed by Booth, Garrett & Blair.
3286	......	0.002	......	......	......	"	29	Analyzed by A. S. McCreath.
625	0.097	0.014	0.43	0.047	0.084	Bethlehem.	6	R. W. Raymond.
628	0.092	0.019	0.48	0.056	0.070	"	6	"
631	0.093	0.017	0.47	0.043	0.080	"	6	"
634	0.097	0.017	0.51	0.044	0.051	"	6	"
639	0.094	0.012	0.44	0.044	0.055	"	6	"
641	0.090	0.017	0.34	0.047	0.069	"	6	"
648	0.096	0.021	0.42	0.047	0.058	"	6	"
650	0.094	0.018	0.49	0.063	0.050	"	6	"
655	0.085	0.012	0.40	0.046	0.072	"	6	"
658	0.088	0.014	0.41	0.045	0.060	"	6	"
660	0.088	0.016	0.39	0.045	0.068	"	6	"
664	0.087	0.016	0.42	......	0.057	"	6	"
667	0.086	0.017	0.39	0.047	0.058	"	6	"
670	0.087	0.017	0.36	0.043	0.065	"	6	"
673	0.090	0.015	0.46	0.053	0.076	"	6	"
......	0.164	0.002	0.792	0.058	0.113	"	6	"
......	0.07	0.007	0.46	0.063	0.033	German.	6	"
......	0.06	0.005	0.53	0.079	0.036	"	6	"
......	0.06	0.009	0.40	0.087	0.06	"	6	"
......	0.06	0.009	0.44	0.074	0.031	"	6	"

TABLE IV.—*Removal of Metalloids in the Bottom-Blown Converter, with Accompanying Slag-Analyses.*

Time After Commencement of Blow.		Removal of Metalloids—Per Cent.					Authority.	Analyses of Corresponding Slags—Per Cent.										
Min.	Sec.	C.	Si.	Mn.	P.	S.		SiO_2.	Al_2O_3.	FeO.	Fe_2O_3	Iron as Shots.	MnO.	CaO.	MgO.	P.	S.	Alkalies.
Pig-iron.		2 98	0.94	1.43	0.100	0.06	Howe. American 39	....	....	....	....	....	....	....	....	....	....	....
2	0	2.94	0.63	0 09	0.104	0.06		42.49	5.63	40 29	4.36	....	6.54	1 22	0.36	0.008	0.009	....
3	20	2.71	0.33	0 04	0.106	0.06		50.26	5.13	34.24	0.96	....	7.90	0.91	0.34	0 008	0.009	....
6	3	1.72	0.03	0 03	0.106	0.06		62 54	4.06	21.26	1.93	....	8.79	0.88	0.34	0.010	0.014	....
8	8	0.53	0.03	0.01	0.107	0 06		63.56	3.01	21.39	2.63	....	8.88	0 90	0.36	0.014	0.008	....
9	10	0.04	0.02	0.01	0.108	0.06		....	....	....	....	....	....	....	....	....	....	....
Steel.																		
9	20	0.45	0.038	1.15	0.109	0 059		62.20	2 76	17.44	2.90	....	13.72	0.87	0.29	0.010	0.011	....
									Al_2O_3 & P_2O_5									
Pig-iron.		3.55	2.39	0.49	0.09	....	King. American 40	....	....	....	....	....	....	....	....	....	....	....
8	0	3 21	1.08	0.15	....	....		62.65	7.98	1.93	....	10.52	15.78	0.65	0.52	....	....	....
15	0	1.25	0.11	0.13	0.09	....		73.24	4.51	0.0	....	8.72	11.83	1.11	0.64	....	....	....
17	0	0.207	0.06	0.13	0.08	....		75.63	5.19	0.0	....	7 70	10.92	0 96	0.38	....	....	....
18	0	0.034	0.04	0 10	....	....		61.30	4.24	13.47	....	9 12	10.82	0.75	0.29	....	....	....
Steel.		0.370	0.06	1.17	0.09	....		64.15	5.71	13.95	....	2.39	12.81	0.75	0.24	....	....	....
									Al_2O_3									
Pig-iron.		3.93	1.96	3.46	0.040	0.018	Bell. English 41	40 95	8.70	0 60	....	....	2.18	30 35	16.31	0.01	0.34	0.32
After slagging		2.465	0.443	1.645	0 040	trace		46.78	4.65	6.78	....	....	37 00	2.98	1.53	0.03	0.04	trace
End of boil.		0.949	0.112	0.429	0.045	"		51.75	2.98	5 50	....	....	37.90	1.76	0 45	0 02	trace	"
End of blow.		0.087	0.028	0.113	0.045	"		46 75	2.80	16.86	....	....	32.23	1.19	0.52	0.01	"	"
Pig-iron.		4.00	1.02	1.83	....	....	Bång-bro. Sw. 42	50.20	3 86	1.80	....	....	5 44	27.22	10.88	....	....	....
3	0	4.30	0.03	0.22	....	....		55.26	2.86	14.20	....	....	26.31	0.62	0.22	....	....	....
4	45	0.90	0.03	0.12	....	....		47.20	2.70	18.52	....	....	31 01	0 38	0.14	....	....	....
5	45	0.10	0.03	0 09	....	....		40.50	2.24	31.19	....	....	25.43	0.32	0.11	....	....	....
Pig-iron.		3.94	1.14	0.64	....	....	Lång-hytt'n. Sw. 42	46 50	12.90	0 90	....	....	.58	32 07	6.75	....	....	....
2	15	4.20	0.04	0 12	....	....		48 76	0.78	34 72	....	....	13.95	2.60	0 24	....	....	....
4	30	1.10	0.03	0.12	....	....		59.82	0.98	21 08	....	....	15.48	3.25	0.30	....	....	....
5	0	0.05	0.01	0.06	....	....		48.48	0.72	35 82	....	....	12.29	2.35	0.21	....	....	....
Pig-iron.		4.49	1.08	0.83	....	....	Sand-viken. Sw. 42	51.00	2.56	0.90	....	....	3.40	31.80	9.03	....	....	....
3	0	3.87	0 03	0.11	....	....		53.44	1.84	20.24	....	....	23.90	0.44	trace	....	....	....
5	0	1.30	0.03	0.09	....	....		57.80	1.94	17.04	....	....	22.80	0 46	....	....	....	....
5	45	0.33	0.02	0.07	....	....		55.76	1.58	18.48	....	....	22.23	0.36	....	....	....	....
Pig-iron.		4.35	0.88	1.15	....	....	Ny-kroppa. Sw. 42	47.16	5.83	0.77	....	....	2.14	21.79	22.18	....	....	....
2	30	4.10	0.10	0.15	....	....		53.26	2.28	13.50	....	....	29 76	0.42	0.23	....	....	....
5	30	1.00	0.05	0.15	....	....		62.34	3.90	9 54	....	....	23.70	0.60	0.28	....	....	....
6	30	0.08	0.04	0.08	....	....		44 52	2 14	30.60	....	....	21.39	.38	0.21	....	....	....
Pig-iron.		4.22	1.06	5.12	....	....	Wes-tanfors. Sw. 42	46.72	4 36	0.70	....	....	11.16	19.10	18.37	....	....	....
4	15	4 20	0.43	3.26	....	....		45.87	3.08	4.20	....	....	46.38	1 26	0.54	....	....	....
8	35	1 30	0.12	0 85	....	....		39.07	2.49	6.24	....	....	52.26	0.70	0.29	....	....	....
9	20	0.55	0.07	0.43	....	....		37.63	2.94	9.45	....	....	48.92	1.00	0.46	....	....	....
																P_2O_5		
Pig-iron.		3.5	1.70	....	1.50	0.05	Basic. Bell. 41a	....	....	....	....	....	....	....	....	....	....	....
3	0	3.6	0.80	....	1.50	0.05		32.6	....	7.26		....	....	....	....	0.60	....	....
6	0	3.4	0.28	....	1.63	0.05		42.6	....	2.57		....	....	....	....	0.15	....	....
9	0	2.4	0.05	....	1.43	0.05		36.0	....	5.91		....	....	....	....	1.60	....	....
12	0	0.09	0.01	....	1.42	0.05		35.6	....	6.17		....	....	....	....	2.61	....	....
14	30	0.075	0.0	....	1.20	0.05		33.0	....	7.89		....	....	....	....	5.66	....	....
16	30	0.0	0 0	....	0.08	0.05		15.6	....	13.43		....	....	....	....	15.06	....	....

TABLE V.—*Removal of Metalloids in the Bessemer Process.*

Time After Commencement of Blow.	Removal of Metalloids—Per Cent.					References and Remarks.
	C.	Si.	Mn.	P	S.	
Min. Sec.						
Pig-iron.	3.52	3.00	1.25	....	....	German method. "Leaving Silicon in the Bath," *Stahl und Eisen*, vol. iii., 1883, pp. 262–264.
5 0	3.6	2.0	0.60	....	....	
10 0	3.3	1.25	0.20	....	....	
15 0	2.5	0.75	0.10	....	....	
20 0	1.0	0.65	trace	....	....	
25 0	trace	0.35	....	....	....	
Pig-iron.	3.5	3.0	0.75	....	....	German method. Same reference.
5 0	3.6	1.75	0.25	....	....	
10 0	3.3	1.25	trace	....	....	
15 0	2.5	0.9	....	....	....	
20 0	1.0	0.7	....	....	....	
25 0	trace	0.5	....	....	....	
Pig-iron.	3.52	1.85	1.93	....	....	German method. Carl Rott. 31
4 30	2.78	1.21	1.69	....	....	
13 0	0.43	0.93	1.00	....	....	
16 0	0.05	0.28	0.37	....	....	
Steel.	0.23	0.27	0.62	....	....	
Pig-iron.	3.57	2.26	0.04	....	....	English method. Carl Rott. 31
6 0	3.95	0.95	trace	....	....	
12 0	1.64	0.47	"	....	....	
18 0	0.19	trace	"	....	....	
Steel.	0.37	"	0.54	....	....	
Pig-iron.	3.270	1.952	0.086	0.048	0.014	English method. Snelus. See *Encyclopædia Britannica*, American ed., vol. xiii., p. 334.
6 0	2.170	.795	trace	0.051	trace	
9 0	1.550	0.635	"	0.064	"	
13 0	0.097	0.020	"	0.067	"	
Steel.	0.519	0.033	0.309	0 053	"	
Pig-iron.	3.5	2.25	1.0	....	....	*Stahl und Eisen*, vol. iii., pp. 262–264.
5 0	3.6	1.0	0.35	....	....	
10 0	3.3	0.5	0.2	....	....	
15 0	3.25	0.2	trace	....	....	
20 0	2.0	0.1	....	....	....	
25 0	trace	trace	....	....	....	
Pig-iron.	3.50	1.50	0.71	1.57	0.16	"Basic Process," *Stahl und Eisen*, vol. iii., pp. 262–264.
5 0	3.55	0.50	0.56	1.60	0.14	
10 0	2.35	0.09	0.27	1.43	0.13	
15 0	0.07	trace	0.12	1.22	0.12	
18 0	trace	....	trace	0.08	0.10	
Pig-iron.	2.97	0.53	0.61	1.22	0.15	"Basic Process," by Müller, at Hörde, *Encyc. Brit.*, p. 346.
4 30	2.480	0.009	0.247	1.250	0.206	
9 15	0.811	0.0	0.0	1.320	0.262	
11 15	0.049	0.0	0.0	0.786	0.262	
13 0	0.0	0.0	0.123	0.021	0.206	

TABLE VI.—*Analyses and Tests of Phosphoric Steels, Containing less than* 0.35 *Per Cent. Carbon.*

Analyses—Per Cent.					Tensile Strength. Lb. per Sq. In.	Elastic Limit. Lb. per Sq. In.	Elongation.		Contraction.	Authority.	Remarks.
C.	Si.	Mn.	P.	S.			Per Cent.	In.			
Low	....	....	High	....	74,790	55,070	25.25	8	48.8	8	Clapp-Griffiths.
"	....	....	"	....	80,030	55,060	23.0	8	26.9	8	" "
"	....	....	"	....	80,270	56,290	22.75	8	30.6	8	" "
"	....	....	"	....	80,420	56,290	17.5	8	14.3	8	" "
"	....	....	"	....	78,730	56,410	14.25	8	15.3	8	" "
0.08	0.01	0.48	0 50	0.09	80,940	58,570	24.0	8	36.4	8	" "
					79,870	58,570	23.25	8	36 4	8	" "
					80,670	60,240	23.0	8	32.5	8	" "
					79,700	59,550	23.25	8	37 6	18	" "
0.10	trace	0.63	0.32	0.03	79,440	58,500	24.00	......	47.0	28	" "
0.12	"	0.81	0.43	0.035	86,230	67,150	18.75	......	31.8	28	" "
0.12	"	0.77	0.55	0.05	79,780	59,650	23.50	......	35.5	28	" "
0.31	"	undet.	0.40	undet.	77,460	0	0.62	......	0.0	28	" "
0.08	"	0.50	0.72	0.03	75,290	69,150	2.25	......	2.6	28	" "
0.13	"	0.73	0.85	undet.	101,540 / 74,234	74,080	9.50	......	9.44	28	" "
....	....	....	0 5 to 0.60	....	70,000	....	25.00	......	36.0	1	" "
0.32	....	1.7	0.31	....	78,300	54,000	14.63	8	27.83	17	Terre Noire, 1874. Mean of over 1,000 cases.
0.34	....	0.58	0.26	....	72,600	47,600	20.45	8	45.05	17	
0.32	....	0.67	0.35	....	80,100	53,000	19.95	8	41.58	17	
0.31	trace	0.75	0.25	trace	80,500	48,600	22.7	4	47.6	17	Terre Noire, 1878.
0.27	"	0.80	0.27	"	80,500	50,000	21.5	4	44.9	17	
0.31	"	0.69	0.40	"	88,200	55,600	22.2	4	46	17	
0.31	0.14	....	0.38	0.03	110,600	....	12.5	......	29.0	17	Heaton steel. Gruner.
0.32	0.21	....	0.34	trace	84,600	....	1.3	......	3.0	17	

TABLE VII.—*Low-Phosphorus Clapp-Griffiths Steel.*

(Carbon and Silicon also Low.)

Tensile Strength. Lb. per Sq. In.	Elastic Limit. Lb. per Sq. In.	Elongation.		Contraction of Area. Per Cent.	Authority.	Remarks.
		Per Cent.	In.			
61,219	....	30.	....	....	4	Tested at Leeds Forge Co.
61,219	....	30.	....	....	4	
65,699	....	25.	....	....	4	
57,420	37,490	28.75	8	51	33	

TABLE VIII.—*Analyses of Pig-Iron Used and Steel Made in the Walrand-Delattre Converter in 1885*[47].

Pig-iron—Per Cent.						Steel—Per Cent.					
Metal.	C	Mn.	Si.	P.	S.	C.	Mn.	Si.	P.	S.	
Acid pig.........	...	tr.–0.5	2.0–2.5	0.06	0.04	0.08–0.12	0.25–0.40	....	0.065	0.02–0.04	Stenay.[a]
Basic, No. 3....	......	trace	2.50	1.80	0.07	0.110	....	trace	0.080	0.040	Hollerich.
" No. 5....	......	"	1.60	1.90	0.08	0.130	....	"	0.008	0.050	"
" mottled..	......	"	0.90	1.99	0.10	0.120	....	"	0.017	0.055	"

[a] This steel has a tensile strength of 53,300 lb. per sq. in., with a minimum elongation of 32 per cent.

TABLE IX.—*Oxidized Materials in the Robert Converter.*

Materials.	Place.	Analyses—Per Cent.											Authority.
		SiO_2.	Al_2O_3.	Fe_2O_3.	FeO.	MnO.	CaO.	MgO.	CO_2.	P_2O_5.	S.	Others.	
Acid converter lining..........	Stenay.	96.75	.....	2.55	....	.....	0.40	... ..	......	... ...	.....	0.30	Garrison. 52
Raw dolomite..	"	0.45	0.36	0.54	.. ...	.. ...	41.35	9.50	48.	.. ....	.....	... ..	Robinson. 53
Acid cinder ...	"	56.88	.... .	.. ...	8.47	9.24	......	.....	......	... ...	......	....	Robinson. 53
Basic cinder....	"	8.30	......	......	31.05	5.16	......	......	......	..... .	... .	.....	Robinson. 53
....	....	....	tr.	. ...	....	mn 2.80	25 80	tr.	.... .	* 16.00	0.17	......	*From 15 to 25 per cent. Garrison. 52

TABLE X.—*Basic-Bessemer Operations in the Robert Converter at Stenay*[52].

	May, 1889.		June, 1889.	
Materials, etc.	Weight Used. Lb.	Per Cent. Used.	Weight Used. Lb.	Per Cent. Used.
Gray iron	427,350	103.6	296,010	79.8
White iron	2,640	0.6	103,950	28.0
Esch	46,970	11.4	31,680	8.5
Scrap	6,776	1.7	7,282	2.0
Spiegel	1,045	0.3	....	....
Ferromanganese	6,230	1.4	5,042	1.4
Total metal used	491,011	119.0	443,964	119.7
Ingots produced	411,917	99.8	366,102	98.7
Scrap produced	740	0.2	5,016	1.3
Total metal produced	412,731[a]	100.0	371,118	100.00
Loss	78,280	19.0	72,846	19.7
Coke used	106,189	25.7	101,965	27.5
Limestone used	14,982	3.6	12,134	3.3
Lime used	66,528	16.1	59,642	16.1
	Blows. 229	Lb. 1,802	Blows. 200	Lb. 1,856
	Days worked. 14	29,486	Days worked. 13	28,547

a Error.

TABLE XI.—*Acid-Bessemer Operations in the Robert Converter at Stenay*[52].

	May, 1889.		June, 1889.	
Materials, etc.	Weight Used. Lb.	Per Cent. Used.	Weight Used. Lb.	Per Cent. Used.
Pig-iron	201,828	87.4	202,686	100.1
Old molds	35,992	15.6	2,200	1.1
Scrap	13,398	5.8	11,770	5.8
Spiegel	2,398	1.0	5,852	2.9
Ferromanganese	4,164	1.8	3,555	1.7
Ferrosilicon	6,769	2.9	6,063	3.0
Total metal used	264,550	114.5	232,126	114.6
Ingots produced	12,452	5.4	3,190	1.6
Castings produced	214,368	92.8	194,381	95.9
Scrap produced	4,169	1.8	4,917	2.5
Total metal produced	230,989	100.00	202,488	100.00
Loss	33,561	14.5	29,638	14.6
Coke used	81,605	35.3	67,443	33.3
Limestone used	8,184	3.5	7,260	3.6
	Blows. 124	Lb. 1,863	Blows. 110	Lb. 1,841
	Days worked. 11	20,999	Days worked. 11	18,408

TABLE XII.—*Pig-Iron Used and Steel Made in the Robert Converter.*

Metal.	Where Used.	Analyses—Per Cent C.	Mn.	Si.	P.	S.	Authority and Remarks.
Acid pig......	Stenay.	3.50	1.00	2.00[a]	0.05	0.05	Garrison. 52
" No. 1.	"	....	1.2	2.00	....	....	Robinson. 53
" No. 2.	"	....	1.3	2.58	....	....	" 53
" No. 3.	"	....	1.3	1.28	....	....	" 53
" No. 4.	"	....	1.2	1.12	....	....	" 53
"	....	....	0.50–tr.	2.00–2.50	0.05–0.06	0.05–tr.	Walrand. 51
" charge	Stenay.	....	....	2.3–2.8	....	....	Hardisty. 5
Basic pig......	"	....	1.80	0.50	2.00–2.50	0.04	Garrison. 52 Said to give best results.
" No. 1.	"	....	....	1.40	2.07	....	Robinson. 53
" No. 2.	"	....	0.90	0.50	2.28	....	" 53
" No. 3.	"	....	....	....	1.77	....	" 53
" No. 4	"	....	1.20	0.42	2.25	....	" 53
"	....	....	1.00–1.50	0.80–1.00	2.00–2.50	0.10–0.02	Walrand. 51
" charge	Stenay.	....	ab. 1.50	0 50–0.80	2 2–2.5	ab. 0.10	....
Acid steel. ..	"	0.07–0.30	ab. 1.00	0.160–0.390	....	....	Garrison. 52
"	Burgess & Co.	0.142	0.86	0.150	0 048	0.053	Robinson 53
"	Stenay.	0.08–0.15	0.30–0.50	....	0.076–0.115	....	Robinson. 53 Ordinary for castings.
"	"	0.27	1.00	0.257	0.070	0.051	Robinson. 53 Car-wheel castings.
Basic steel...	"	0.08	0.30	....	0.019	....	Robinson. 53
" ...	"	0.12	0.40	0.009	0.065	....	" 53
" ...	"	....	0.86	nil.	0.051	....	" 53
" ...	....	0.10–0.08	0.40–0.25	....	0.06–0.02	0.03–tr.	Walrand. 51
Ferromang...	Burgess & Co.	5.70	66.00	....	....	....	Robinson. 53
"	Stenay.	....	71.10	0.15	0.01	....	Garrison. 52
Ferrosilicon.	Burgess & Co.	....	5.13	12.10	....	....	Robinson. 53
"	Stenay.	....	1.30	10.00	0.003	0.03	Garrison. 52

[a] Must not be below 1.4 per cent. at cupola.

TABLE XIII.—*Tests of Bessemer Steel Made in the Robert Converter.*

Mark.	Physical Tests.						Chemical Analyses—Per Cent.					Steel.	Tests Made by	Authority.
	Tensile Strength. Lb. per Sq. In.	Elastic Limit. Lb. per Sq. In.	Elongation. Per Cent.	Elongation. In.	Reduction of Area.	Drop Test.	C.	Mn.	Si.	P.	S.			
	74,123	....	28.0	?	....	14 blows.	0.225	1.0	0.150	....	....	Acid steel-castings for the French navy.		Robinson. 53
	70,132	....	28.2	?	....	24 "	0.240	0.7	0.070	....	....			
	99,068	....	7.0	?	....	6 "	0.250	1.0	0.127	....	....			
	75,548	....	24.0	?	....	12 "	0.250	1.1	0.190	....	....			
892	55,690	32,400	27.4	10	58.3	....						Basic.	David Kirkaldy & Son.	Garrison. 52
890	55,045	30,700	27.9	10	56.7	....								
888	50,865	28,300	28.8	10	59.9	....								
894	49,810	28,100	35.3	10	68.2	....								
Average..	52,852	29,875	29.8	10	60.8	....								
898	57,590	41,500	24.8	10	66.6	....								
897	56,910	35,700	26.4	10	70.6	....								
896	51,520	31,800	27.3	10	75.0	....								
Average..	55,340	36,333	26.2	10	70.7	....								
1	56,000	....	39.00	2	59.84	....						Tin bar. Basic. Made at Blaenavon Works, England.	Blaenavon Works.	Garrison. 52
2	56,000	....	40.62	2	62.88	....								
3	58,000	....	37.5	2	62.88	....								
4	56,000	....	40.62	2	62.83	....								
5	54,000	....	40.62	2	62.88	....								
6	56,000	....	39.00	2	59.84	....								
1	60,000	....	31.25	2	59.84	....						Basic billets Made at the same place.	"	
2	58,000	....	35.31	2	59.84	....								
Average of 7 tests.	58,557	....	39.19	2	63.59	....	0.105	0.442	tr.	0.056	0.047	Basic steel. Made at the same place.	"	

Table XIV.—*Installations of Tropenas-Bessemer Converters.*

57, 58, 20

<table>
<tr><th rowspan="2">Country.</th><th colspan="2">1896.</th><th colspan="2">1898.</th><th colspan="2">1900.</th></tr>
<tr><th>Number of Plants.</th><th>Number of Converters.</th><th>Number of Plants.</th><th>Number of Converters.</th><th>Number of Plants.</th><th>Number of Converters.</th></tr>
<tr><td>England..........</td><td>1</td><td>3</td><td>3</td><td>8</td><td>..............</td><td>..............</td></tr>
<tr><td>France............</td><td>2</td><td>..............</td><td>3</td><td>4</td><td rowspan="6">20</td><td rowspan="6">50</td></tr>
<tr><td>Belgium..........</td><td>1</td><td>..............</td><td>1</td><td>4</td></tr>
<tr><td>Russia.............</td><td>2</td><td>..............</td><td>3</td><td>7</td></tr>
<tr><td>Austria............</td><td>1</td><td>..............</td><td>1</td><td>2</td></tr>
<tr><td>Poland............</td><td>1</td><td>..............</td><td>1</td><td>2</td></tr>
<tr><td>Germany.........</td><td>0</td><td>0</td><td>1</td><td>2</td></tr>
<tr><td>United States...</td><td>0</td><td>0</td><td>1</td><td>1</td><td>9</td><td>13</td></tr>
<tr><td>Switzerland......</td><td>0</td><td>0</td><td>1</td><td>3</td><td>..............</td><td>..............</td></tr>
<tr><td>Total............</td><td>8</td><td>..............</td><td>15</td><td>33</td><td>..............</td><td>..............</td></tr>
</table>

TABLE XV.—*Tests of Steel-Castings—Tropenas.*

Tensile Strength. Lb. per Sq. In.	Elastic Limit. Lb. per Sq. In.	Elongation. Per Cent.	Elongation. In.	Reduction of Area.	Appearance of Fracture.	Annealed?	Chemical Analyses—Per Cent. C.	Mn	Si.	P.	S.	Steel Made by.	Tests Made by.	Authority.
61,800	...	35.5	2	54.8	...	...	...	...	...	...	...	Edgar Allen & Co.	Thos. Nash.	57
64,700	...	34.0	2	52.4	...	...	...	...	...	...	...	“	“	57
66,100	...	32.5	2	52.4	...	...	...	...	...	...	...	“	“	57
69,800	...	30.0	2	42.0	...	...	...	...	...	...	...	“	“	57
67,900	...	23.3	6	49.6	...	...	...	...	...	...	...	“	“	57
66,600	...	29.0	2	42.0	...	...	...	...	...	...	...	“	“	57
65,850	...	24.7	3	36.4	...	...	...	...	...	...	...	“	“	57
65,500	...	22.3	6	33.6	...	...	...	...	...	...	...	“	“	57
65,100	...	19.0	8	18.4	...	...	...	...	...	...	...	“	“	57
62,000	...	34.0	2	52.4	...	...	...	...	...	...	...	“	“	57
61,800	...	31.3	3	49.6	...	...	...	...	...	...	...	“	“	57
60,800	...	24.8	8	52.4	...	...	...	...	...	...	...	“	“	57
65,700	...	33.0	2	49.6	...	...	...	...	...	...	...	“	“	57
69,350	...	28.0	2	36.4	...	...	...	...	...	...	...	“	“	57
72,000	...	32.0	2	47.2	...	...	...	...	...	...	...	“	“	57
66,400	...	35.0	2	54.8	...	...	...	...	...	...	...	“	“	57
78,100	...	28.5	2	33.6	...	...	...	...	...	...	...	“	“	57
65,500	...	32.0	2	49.6	...	...	...	...	...	...	...	“	“	57
67,200	...	31.0	2	47.0		(Average of 12 tests.)							For the Admiralty.	57
66,600	...	33.0	2	53.0		(“ “ 7 “)								57
70,600	...	34.5	2	54.3	Silky.	...	...	...	...	...	...	“	Thos. Nash.	60
72,900	...	33.5	2	52.4	Silky; fibrous.	...	...	...	...	...	...	“	“	60
58,200 to 67,200	...	27 to 37	2	...	...	...	...	...	...	...	...	“	“	60
74,000	...	30.0	2	52.4	...	...	...	...	...	...	...	“	“	60
72,400	...	35.0	2	50.1	...	...	...	...	...	...	...	“	“	60
71,400	...	32.5	2	52.4	...	...	...	...	...	...	...	“	“	60
63,250	...	35.5	2	54.8	...	...	...	...	...	...	...	“	“	60
111,200	...	10.0	2	8.4	...	...	...	...	...	...	...	“	“	60
64,900	...	36.0	2	54.8	...	...	...	...	...	...	...	“	“	60
68,400	32,150	32.0	2	39.5	Silky.	Yes	0.27	0.78	0.25	0.051	0.034	American Hoist and Derrick Co.	In presence of a gov't inspector.	61
71,900	42,900	28.5	2	35.5	“	“	0.28	0.81	0.28	0.050	0.039	“	“	61
70,100	40,050	31.5	2	36.0	“	“	...	...	...	...	...	“	“	61
66,950	37,800	32.0	2	36.0	“	“	0.26	0.76	0.23	0.049	0.033	“	“	61
67,550	40,000	31.5	2	40.5	“	“	...	...	...	...	...	“	“	61
60,500	...	30.5	2	31.5	“	“	...	...	...	...	...	“	“	61
69,000	32,200	32.5	2	44.2	“	“	0.28	0.76	0.29	0.051	0.037	“	“	61
66,800	33,500	33.4	2	48.5	“	“	0.24	0.97	0.26	0.048	0.024	“	“	61
66,650	41,050	34.0	2	40.0	“	“	...	...	...	...	...	“	“	61
63,800	29,350	38.5	2	50.8	“	“	0.24	0.78	0.23	0.053	0.033	“	“	61
68,420	31,378	31.5	2	45.5	“	“	0.24	0.82	0.25	0.052	0.039	“	“	61
66,350	36,250	32.5	2	37.5	“	“	...	...	...	...	...	“	“	61
61,200	29,000	36.0	2	52.5	“	“	0.25	0.75	0.21	0.045	0.039	“	“	61
67,100	30,000	37.5	2	53.5	“		...	...	...	...	...	“	“	61
68,385	...	31.8	2	44.9	(Average of 42 tests above.)								“	
67,337	35,263	33.0	2	42.8	(Average of last 14 tests above.)								“	
76,000	42,000	32.0	?	42.0	...	...	...	...	...	...	...	Green sand casting.	...	64
65,000 to 80,000	38,000 to 45,000	28 to 36	?	35 to 55	...	...	...	...	...	...	...	...	...	64

Table XVI.—*Tests of Open-Hearth Steel-Castings.*

Tensile St'h. Lb. per Sq. In.	Elastic Limit. Lb. per Sq. In.	Elongation. Per Cent.	Elongation. In.	Reduction of Area. Per Cent.	Appearance of Fracture.	Annealed?	Chemical Analyses—Per Cent. C.	Mn.	Si.	P.	S.	Steel Made by.	Tests Made by.	Authority.
67,500	29,000	27.0	2	32.5	....	Yes.	0.31	0.47	0.25	0.048	0.027	Acid.	Benj. Atha & Co.	Benjamin Atha & Co. in presence of an inspector.
65,000	35,000	34.0	2	50.6	....	"	0.26	0.74	0.28	0.051	0.027	"		
70,000	43,000	20.0	2	35.1	....	"	0.21	0 45	0.22	0.058	0.030	"		
65,500	38,500	34.0	2	43.4	....	"	0.20	0.59	0.26	0.023	0.027	Basic.		
65,500	41,500	32.5	2	45.7	Silky.	"	0.17	0.64	0.25	0 031	0.020	"		
65,500	36,000	33.5	2	53.1	"	"	0.19	0.62	0.24	0.027	0.025	"		
89,000	46,000	21.0	2	19.9	50 per ct. gr.	"	0.21	0.57	0.21	0.035	0.023	"		
64,000	32,500	35.0	2	54.7	Spongy.	"	0.20	0 69	0.25	0.028	0.032	"		
62,800*	33,500	16.0	2	27.1	Gr. specks.	"	0.18	0.71	0.22	0.039	0.031	"		
80,000	41,000	26.0	2	35.7	70 per ct. gr.	"	0.26	0.74	0.25	0.071	0.054	Acid.		
55,000	37,000	30.5	2	46.3	Silky.	"	0.26	0.70	0.21	0.046	0.032	Basic.		
69,000	35,000	34.0	2	38.2	....	"	0.30	0.78	0 17	0 035	0.034	"		
68,500†	36,000	10.5	2	13.0	....	"	0.33	0.75	0.28	0.025	0.030	Acid.		
82,500	43,500	16.0	2	22.0	... .	"	0.40	0.74	0.34	0.050	0.036	"		
78,500	43,000	17.5	2	21.0	....	"	0.41	0.55	0.30	0.058	0.028	"		
81,500	41,500	18.0	2	22 4	....	"	0.41	0.56	0.28	0.045	0.041	"		
91,000	46,000	20.0	2	26.5	....	"	0.22	0.90	0.30	0.063	0.044	"		
85,000	45,000	17.0	2	22.4	....	"	0.35	1.11	0.26	0.045	0 041	"		Private notes.
72,514	39,056	24.6	2	33.9	(Average of the 18 tests above.)									
					* After reannealing this same steel gave the following.									
*67,000	35,000	17.5	2	27.5										
					† After reannealing this same steel gave the following:									
†70,000	35,000	24.0	2	35.1										
†70,500	34,000	25.5	2	33.5										

Table XVII.—*Tests of Open-Hearth Steel-Castings.*

Tensile Strength. Lb. per Sq. In.	Elastic Limit. Lb. per Sq. In.	Elongation. Per Cent.	Elongation. In.	Reduction of Area. Per Cent.	Annealed?	Steel Made by.	Remarks.
67,000	30,000	28.8	2	46.3	Yes.	American Steel-Casting Co.	
68,500	32,000	29.0	2	47.8	"		
67,000	30,500	30.6	2	52.8	"		
70,500	30,500	28.8	2	41.0	"		
72,500	33,500	27.2	2	42.5	"		
65,500	30,500	29.8	2	44.9	"		
65,000	30,000	30.5	2	54.1	"		
69,500	32,000	27.0	2	48.6	"		65
65,000	29,000	26.0	2	50.0	"		
65,000	30,000	30.2	2	51.1	"		
68,000	30,000	28.3	2	42.2	"		
65,500	30,000	26.0	2	50.9	"		
68,500	33,500	34.3	2	43.7	"		
66,500	29,500	29.2	2	48.0	"		
69,000	32,500	28.0	2	41.9	"		
67,533	30,900	28.9	2	47.1	"		Average

TABLE XVIII.—*Tests of Crucible Steel-Castings.*

Tensile Strength. Lb. per Sq. In.	Elastic Limit. Lb. per Sq. In.	Elongation. Per Cent.	Elongation. In.	Reduction of Area. Per Cent.	Steel Made by.	Remarks.
59,700	45,500	29.0	4	75 0	Mm. Holtzer et Cie.	62
67,400	48,200	27.0	4	68.0		
76,100	53,200	20.0	4	60.0		
82,500	59,900	17.5	4	57.0		
88,600	58,600	14.0	4	50.0		
95,300	73,900	10.5	4	44.0		
78,267	56,550	19.7	4	59.0		Average

TABLE XIX.—*Analyses of Side-Blown Converter-Gases.*

Sample No.	Time After Beginning of Blow.	Analyses—Per Cent. CO.	CO_2.	O.	N. & H.	Calculations from Analyses—Per Cent. Total O.	N.[a]	O. Entering.	O. Burning Si & Fe & Mn.
1	4 min., flame starts......	0.0	8.2	1.1	90.7	7.1	88.7	23.6	16.5
2	10 min., boiling............	0.3	24.3	0.4	75.0	18.3	73.0	19.4	1.1
3	12 min., shortening[b]......	0.4	8.8	0.2	90.6	6.8	88.6	23.5	16.7
4	17 min., after first drop..	10.7	13.0	0.2	76.1	15.8	74.1	19.7	3.9
.....	21 min., end of blow.								

[a] H. being estimated as 2 per cent.

[b] *i. e.*, just before the first drop. There are two drops to the flame in this operation, the second marking the end.

TABLE XX.—*Analyses of Bottom-Blown Converter-Gases.*

Time After Starting Blow.	Per Cent. CO.	CO_2.	O.	H.	N.	Reference.
2 min.	....	10.71	0.92	....	88.37	Sir Lothian Bell.37
4 "	3.95	8.59	....	0.88	86.58	
6 "	4.52	8.20	....	2.00	85.28	
10 "	19.59	3.58	....	2.00	74.83	
12 "	29.30	2.30	....	2.16	66.24	
14 "	31.11	1.34	....	2.00	65.55	
18 "	End of blow.					
3 to 5 min.	....	9.127	4.762	....	86.111	38
9 to 10 "	17.555	5.998	1.699	0.908	73 840	
21 to 23 "	19.322	4.856	0.967	1.120	73.735	
26 to 27 "	14.311	1 853	0.550	1.699	81.587	
2 to 3 min.	....	6.608	7.256	....	86.137	38
8 to 10 "	15.579	5.613	1.296	1.112	76.400	
12 to 15 "	25.580	4.144	0.980	1.040	68.256	
17 to 19 "	25.606	2.995	1.318	1.120	68.961	

APPENDIX.

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Geology of Southwestern Texas.

BY E. T. DUMBLE, HOUSTON, TEXAS.

(New Haven Meeting, October, 1902.)

CONTENTS.

INTRODUCTION.

THERE is, perhaps, no part of Texas which has had so little attention from geologists as the area lying south of the line of the Southern Pacific railway, between the San Antonio river and the Rio Grande. This is, comparatively, a small portion of Texas, and yet, containing as it does more than 30,000 square miles, it is larger in extent than either South Carolina or West Virginia, and nearly as large as Indiana. About all of the reports on this area, which have been published, are concerned with the Cretaceous deposits of its extreme northwest corner and the belt immediately adjacent to the Rio Grande river.

The writer's field-work on which the following statements are based was as follows:

In 1889, I accompanied Dr. R. A. F. Penrose, Jr., in a boat-trip from Eagle Pass to Edinburgh, the main results of which were given by Dr. Penrose in the *First Annual Report of the Geological Survey of Texas*, but which are here given more fully and with a somewhat different interpretation.

In 1891, starting from Cotulla, I made a reconnaissance westward to Carrizo Springs, and northward from that point to the Eagle Pass and Batesville road-crossing on the Nueces. We crossed to Batesville and then followed the Leona river to Uvalde.

In 1892, in company with Mr. J. A. Taff, I made a hasty trip from San Diego to the Picacho and Loma Alta hills, and examined the beds around San Diego.

In August, of the same year, I made a trip from Beeville, with Mr. F. S. Ellsworth as aid, by way of Oakville and Dinero to San Diego.

In 1893, I started with a well-equipped party from LaCoste,

on the Southern Pacific railroad, ran a transit-line and line of levels to the San Antonio and Aransas Pass railroad at Wade, and made as complete a geological section as could be done in the time at my command. A second line was run and section made from San Diego to Pearsall. In September, I made a trip to Laredo, and from there to Ochoa, on the Mexican National railroad. From this point I visited Los Ojuelos and examined the springs, the scarp of the Bordas east of it, and the various wells between Ochoa and Peña, including the artesian well of Mr. Bruni.

Since that time, Messrs. W. Kennedy and W. F. Cummins have been over the coastal portion of the region, and I am indebted to them for some additional details, which have been still further added to by my trips during the present field-season.

Figs. 1 and 2 give a map and sections of the territory under consideration.

I. Topography.

This area may be most concisely characterized as a gently inclined plain, sloping from the northwest toward the Gulf coast. The surface of this plain has been eroded by atmospheric agencies to produce its present varied character of plateau and valley and hill.

Beginning in low-level prairies at the coast the ascent is very gradual for the first 50 miles, but after that it increases more rapidly, and gently swelling ridges or broad plains sweep northward to the escarpment south of the Nueces river, which is known to the citizens by its Spanish name of the "Bordas." So steep is the descent to the north from the top of this plain that it is often difficult to find a suitable place for a wagon-road into the valley, which lies from 100 to 300 ft. below. The country then becomes rolling, and, after the Nueces is crossed, again rises gradually toward the north and west, cut here and there by its many creeks and river-channels.

The principal topographic divisions of this region are:

The Nueces Basin.

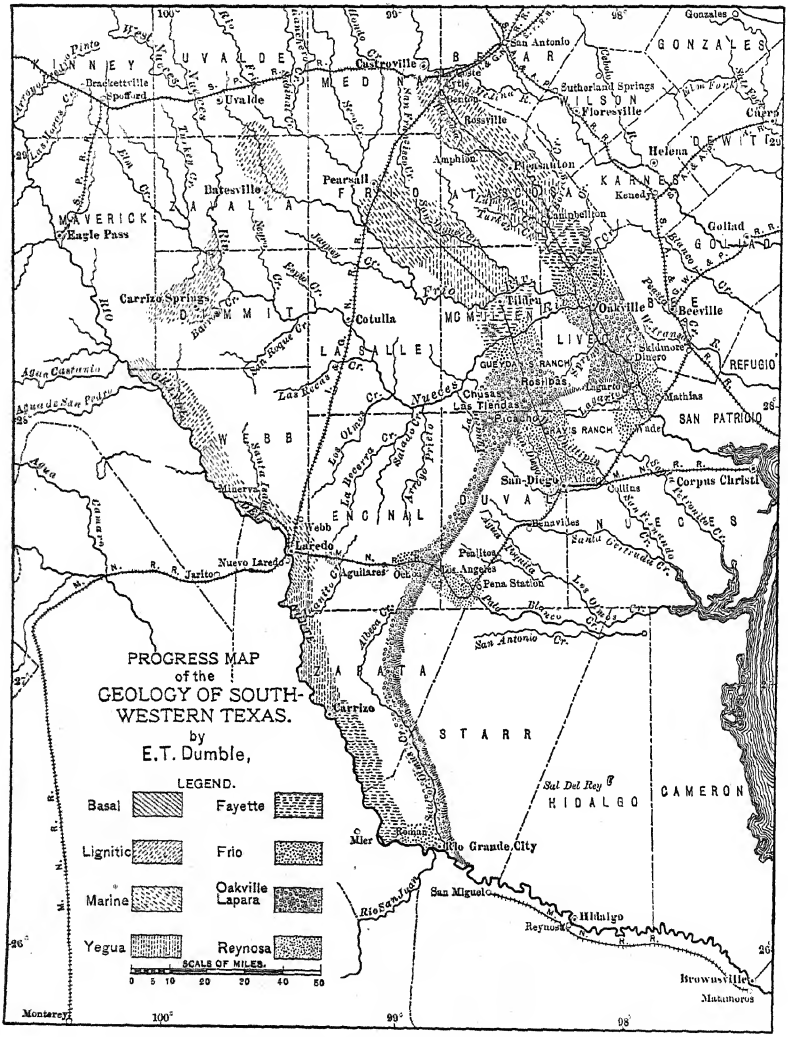
The Coastal Slope.

These are bordered on the east by the valley of the San Antonio river, which occupies a comparatively narrow strip, and on the west by the Rio Grande, which flows in a correspondingly narrow valley.

The Nueces Basin.—Along the Southern Pacific railroad,

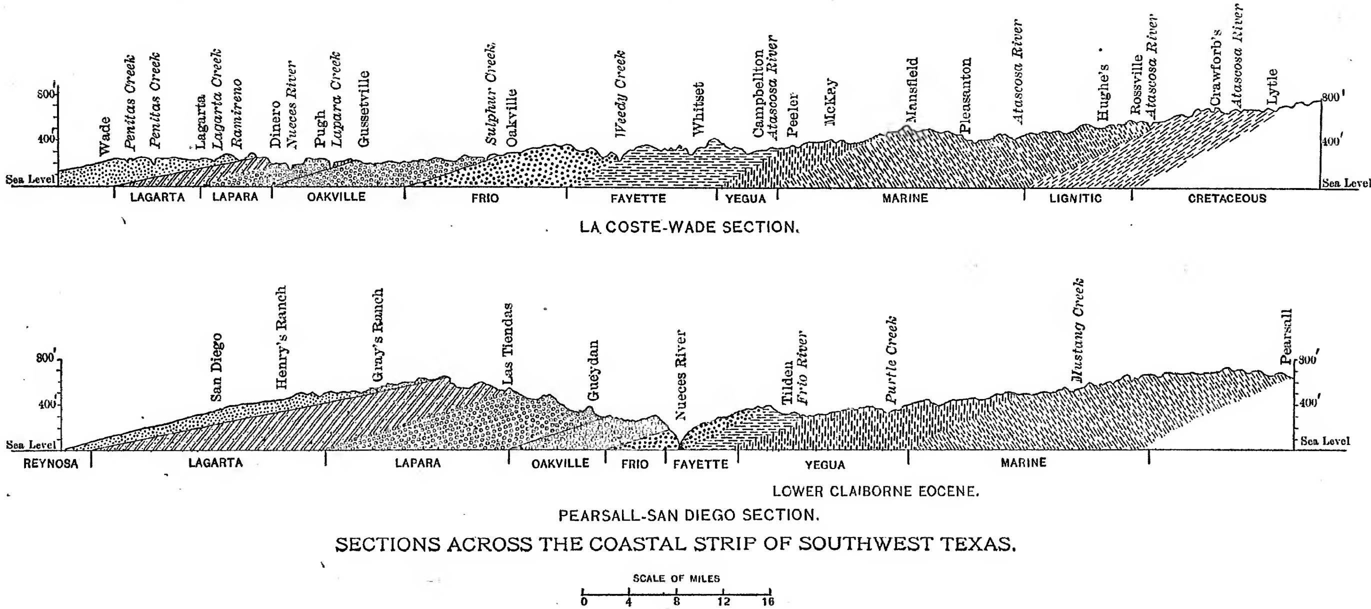
which forms the northern limit of the area, the elevations above sea-level, as given by the profiles, begin at San Antonio at 686 ft. At Dunlay, 40 miles west, the altitude has risen to 1,000 ft.,

Fig. 1.



and from Dunlay to Spofford it varies between that and 900 ft. According to a line run 50 miles, or more, south of this, crossing the International and Great Northern railroad at Twohig, and having Eagle Pass as its terminus, the divide between

Fig. 2.



SECTIONS ACROSS THE COASTAL STRIP OF SOUTHWEST TEXAS.

the Nueces and the Rio Grande is 810 ft. high. Carrizo Springs on this line has an elevation of 530 ft.

The International and Great Northern railroad also crosses this area, running from San Antonio to Laredo. From San Antonio, 661 ft., it rises to the divide between the San Miguel and Frio rivers, just south of Moore. This point has an elevation of 780 ft. Thence the grade descends to 400 ft. at the crossing of the Nueces river, and then ascends again to the top of the divide between that river and the Rio Grande, near Webb, where an elevation of 718 ft. is reached. From here to Laredo, 421 ft., the descent is gradual. This cross-section of the Nueces basin gives a difference of elevation of from 318 to 380 ft. between the divides and the river-bottom.

The river itself has the following elevations:

Crossing of Southern Pacific railroad, about 900 ft.

Crossing east of Carrizo Springs, about 500 ft.

Crossing International and Great Northern railway, 380 ft.

Crossing San Diego and Tilden wagon-road, 150 ft.

Dinero, Live Oak county, 107 ft.

The Coastal Slope.—The Coastal Slope occupies, probably, one-third of this entire area. It has for its northern border the Bordas escarpment, which is a continuation of the adobe-capped ridges found at Goliad and Belleville, remnants of which may also be found, not only on the divides within the Nueces basin itself, but also on those between its drainage and that of the San Antonio river and of the Rio Grande.

At Dinero, the northern border of this plain has an extreme elevation of 400 ft. From this point it gradually rises in its southwest course through Live Oak, Duval and Encinal counties, and crosses the line of the Mexican National railroad between Aguilares and Los Angeles, in a north and south course, with an elevation of over 800 ft. It then bends a little westward, and, gradually sloping downward, passes through the northeast corner of Zapata and southwest portion of Starr counties, and reaches the Rio Grande below Rio Grande City. At Reynosa, the typical locality of its most persistent surface-rock, it is only from 40 to 50 ft. above the river. In general terms, the northern border of the plain is parallel to the present coast-line of the Gulf, and from 75 to 100 miles from it.

The Mexican National railroad, from Corpus Christi to

Laredo, crosses this plateau, and the elevations of the principal stations on the line will give an idea of the character of the slope:

Corpus Christi,			40 ft.
Alice,	42	miles,	190 "
San Diego,	10	"	314 "
Benavides,	18	"	386 "
Realitos,	15	"	440 "
Peña,	13	"	550 "
Los Angeles,	16	"	823 "
Aguilares,	16	"	650 "
Pescadito,	13	"	588 "
Brennans,	10	"	490 "
Laredo.	7	"	438 "

Thus the coast-prairies proper extend to near Alice, from which place there is a more rapid rate of elevation to Los Angeles, which is one of the highest points on the line. From here the descent to Aguilares is rapid, the railroad utilizing one of the very few places where a natural slope gave it a route down into the valley. From Aguilares the grade is still downward, but with much more gradual slope, to Laredo.

The surface of this plain is gently rolling, as a whole, although in places there stretches around the observer, as far as eye can reach, a vast and apparently level plain or basin-like expanse, bearing a striking resemblance in topographic aspect to the Llano Estacado, with which it has also close geological relationship.

Streams.—The San Antonio river, which forms the eastern border of the territory, has within it a very limited drainage-area, and the few tributary creeks and branches are, as a rule, short and unimportant.

The Rio Grande, also, although it carries a large body of water, drains a very small portion of the area, and, while it has several large affluents from the Mexican side, such as the Rio Salado, Alamo and San Juan, it can boast of no rivers on the Texas side, nor even of any large creeks, south of Eagle Pass, except the Chacun, Juanita and Olmos, no one of which has a constant flow.

The Nueces river drains nearly two-thirds of the entire area, and in its course from the Cretaceous table-land to the Gulf has greatly exaggerated the tendency of all of the rivers of Texas,

having their source in or north of the Tertiary belt, and a general southeastward flow, to be deflected eastward or northeastward in passing through the Fayette and Oakville sands. Thus, from its source in the Nueces canyon, in Edwards county, it flows south and southeast to the southern part of LaSalle county, where, suddenly swinging at right-angles to its former course, it flows northeast for more than 50 miles until, at Oakville, it resumes its normal course even more abruptly than it left it. It has numerous tributaries, among the principal of which are the Frio and Atascosa rivers, Elm, Los Raices, Olmos, Salado, Sulphur, Gamble, Lapara, Ramirena, Lagarto and Penitas creeks.

The wanderings of the Nueces itself through this area are, in part, recorded by the lakes which still exist along some portions of its course, especially in La Salle and Dimmit counties, where several long and comparatively narrow bodies of water are found. Some of these, like Lake Espintosa, are directly connected with the present channel and are still utilized by the water in time of flood, while others have been entirely forsaken and are now simply indications of the course of the river at some former time. The character of the deposits along the lower part of its course shows that this part of the basin has also been the site of many lakes, which have since been filled up and again exposed, by the erosive action of the river or its tributaries, in still later times. Indeed, it would appear in places as if the river had been a chain of lakes stretching in and out among the higher grounds which formed its banks, and which now constitute the second bottoms and the highlands.

That the river still changes its course, under certain conditions, is well shown at a locality 8 miles south of Oakville, where it has forsaken a direct channel of only a few hundred yards in length and cut a new one, with a great double-bend, which has a length of more than 3 miles. This change was caused, partly, at least, by a hard sandstone which forms the bottom of the old channel.

For all that the drainage-channels of the Nueces make such a goodly show as water-courses upon the map, it frequently occurs that, at certain seasons of the year, even if not for the principal portion of it, many of them are perfectly dry, and at the

surface, at least, innocent of moisture. Indeed, according to the statements of some of the older citizens, a great alteration has taken place in some of these channels during the last forty years. They claim that, before the settlement of the country, many of these creeks were constant in their flow, and the grass, beginning at the water's edge, stretched out on either side of them over wide open prairies. The advent of the stockmen into this ideal grazing-region gradually worked a change in the conditions. The cattle ate down the grass and broke up the turf by tramping, so that the strong winds which prevail, and the heavy rains which fall occasionally, had full sweep at the underlying sand. Together, these filled up the channels of the creeks to such an extent that they now carry water on the surface only after heavy or continued rains, although an abundant supply may be had in many of them by sinking shallow wells in their beds. During one of the trips I made, the Nueces itself was dry in several places.

The same causes which brought this about have also effected a change in the plant-growth, and now much of the territory which was formerly open prairies is grown up in mesquite thickets, and sometimes chapparral, so dense as to be practically impenetrable, even on horseback.

The series of streams which have their origin in the Coastal Slope comprise the Santos, Olmos, Santa Gertruda, San Fernando and Santa Petronelle creeks, on the west of the Nueces and the Aransas river, between that stream and the San Antonio.

II. Geology.

Beyond the fringe of Cretaceous rocks, which occupies the northwestern corner of the area, the deposits are all of Tertiary and post-Tertiary age. They consist of beds of sand, clay and gravel, with limestones, brown coal and lignite, gypsum, sulphur, iron and other minerals, and were deposited in their present position under conditions somewhat similar to those which now obtain along the Gulf coast. Since their deposition they have not been subjected to any disturbance of sufficient magnitude to alter their relative positions, the numerous elevations and depressions which took place during their formation having been so gradual that very little faulting on a large scale has been observed in them. The erosion which followed

their final elevation above sea-level has exposed the edges of these successive rock-sheets so that they now crop out in belts of varying width, which have a general parallelism to the present shore-line. Starting from the north and west, and traveling toward the Gulf, we pass from the Cretaceous rocks to the lowest or oldest Tertiary; thence, as we go seaward, we pass, successively, later and later, beds of the Tertiary and post-Tertiary deposits until the coast is reached.

These deposits have been grouped in the following series:

Pleistocene, . . .	Coast Clays.	
	Equus Beds.	
Neocene, . . .	Reynosa.	
	Lagarto.	
	Lapara,	Blanco.
	Oakville,	Grand Gulf?
Eocene, . . .	Frio,	Lower Claiborne.
	Fayette,	
	Yegua,	
	Marine,	
	Lignitic,	Lignitic.
	Wills Point,	Midway.

The stratigraphy of the coastal deposits has not yet been fully worked out, nor have their exact relations to similar deposits in other areas been determined. The great area which they cover, amounting to one-third of the entire State, the variable character of the deposits, the scarcity of fossils, and the infrequency of extensive exposures, have all had their share in delaying the work. The studies by Prof. Gilbert D. Harris on the fossils collected from our Eocene deposits, and of the materials obtained from the deep well at Galveston, indicate that our Eocene corresponds in age with the lower portion of the Alabama section. As yet, no deposits have been described which are certainly representatives of the Eocene of Alabama above the Lower Claiborne,* nor of the Miocene below the upper members of that system. Nor is this hiatus eliminated by the beds described in the new divisions which are proposed here, but is rather emphasized thereby, since the conditions of the eastern part of the State are shown to continue to its western border.

* Since this was written, fossiliferous beds belonging to the Jackson have been found in East Texas by Veatch.

Eocene.

Basal Beds.—East of the Colorado, the basal beds consist of stiff, laminated clay, yellow, red, blue or bluish-green in color, with some laminæ of sand, boulders and highly calcareous indurated strata of nodular structure, containing in places many fragments of shells. The boulders are irregularly distributed through the clay, and sometimes form continuous bands for considerable distances. Another phase assumed by the lime which they contain is the small cauliflower-like concretions which abound in certain beds. Gypsum crystals are also plentiful.

The contact of the Tertiary with the underlying Cretaceous is found on the Rio Grande, at Webb Bluff, the section of which is as follows:

	Ft.	In.
1. Gravel, ...	2 to 3	
2. Argillaceous sandstone, white and glistening, with some mica, foliations of ferruginous material, dark streaks and specks of lignitic matter and concretions of calcareous sandstone, ...	30	
3. Thin seam and detached masses of Grahamite, mixed with gypsum and sulphur, ...		3 to 6
4. Greensand marl, with numerous marine Tertiary fossils; nodules of carbonate of lime and "cannon-ball" concretions of altered glauconitic materials, with fossils, including *Venericardia alticostata*, Con., ...	7 to 8	
5. Blue joint-clay, of lighter color where dry and weathering yellow. Very similar to other clays of the upper Escondido beds, but, so far as observed, unfossiliferous; as exposed, ...	10	

The fossils found in No. 4 and determined by Mr. Harris are: *Pleurotoma* (Drillia) *nodocarinata* Gabb, *Volutilithes* (?) *rugatus*, Con.; *Cypræ sp.*

If beds of this division occur in the area under consideration east of this limited exposure on the Rio Grande, they have not yet been distinguished from the Timber Belt beds. At all other localities, so far as our observations go, instead of beds of clay we have beds predominatingly sandy and containing few fossils, the character of which certainly groups them with the Lignitic beds. Thus it would appear that we have here an overlapping of the Basal beds by the Lignitic.

Lignitic Stage.—These beds are, for the most part, composed of siliceous sand, but also contain glauconitic sands, lime and

clays of various colors. Brown coal and lignite beds, varying from a few inches to 10 and 12 ft. in thickness, are of frequent occurrence, and the sands and clays are often so impregnated with vegetal matter as to give rise to traces and even deposits, of some economic value, of oil and natural gas.

The sands are usually much cross-bedded, gray, blue, black, white, yellow, brown or red in color, and often contain specks or grains of glauconite. The lime exists in the form of nodules, concretions and beds of siliceous limestone. They contain gray or brown mica in considerable quantities and are very variable, blending by almost insensible gradations, both vertically and horizontally, into clay, or, more properly speaking, sandy clay-beds. The clays are also of various colors, according to the amount of ferruginous or vegetal matter they contain, and occur both laminated and in massive beds.

Silicified wood is common. Iron occurs as pyrites, and also as iron carbonate, which is found in nodules, strings and small seams of clay ironstone. In places it is oxidized and takes on the character of the laminated ores of East Texas.

The lowest member of this stage is a series of gray micaceous sands and sandstones, with chocolate or lignitic clays and brown coals or lignites overlain by a series of red and white clays with iron. This is overlain by yellow and white sand-rock and white sandstone, with ferruginous concretions and grit with clay inclusions—the Carrizo sands of Owen and Queen City beds of Kennedy. For the reason that a great part of our lignite-deposits occur in these beds, they have been given the name "Lignitic," and, as proved by the paleontological work of Prof. Harris, they belong to the Northern Lignitic of Hilgard's Mississippi section. Outcrops of materials belonging to these beds were observed in Medina, Atascosa, Zavalla, Dimmitt and Webb counties.

Atascosa Sections.—Two miles west of La Coste, on the line of the Southern Pacific railroad, we found a good exposure of the clays, sands and sandy clays of the Navarro beds (Cretaceous). The following is the section:

	Ft.
1. Yellow sands and sandy clays indurated in places, . .	8 to 10
2. Yellow limestone, containing many fossils—*Anomia sp. ind.*, *Trigonarca cuneata*, *Ostrea larva*, and others undetermined,	0.5 to 1
3. Clays, with ferruginous concretions, ...	4 to 5

Between this point and the first of the Tertiary deposits, south of it, we found no exposures of any kind, although just west of the last section the soil changed to the steel-gray sandy character, which marks the Tertiary where we observed it.

Three miles west of the above Cretaceous locality, and 5 miles from La Coste, we found our first recognizable Tertiary, at an elevation, according to the levels of the Southern Pacific railroad, of 805 ft. It consisted of quartzitic sandstone, yellow to gray in color, heavy-bedded at the bottom of the exposure, but becoming more thinly stratified and lighter in color toward the top, where it is almost laminated. This exposure has a thickness of 20 ft., and continues southward for a quarter of a mile along a hollow which belongs to the San Miguel drainage. The dip, which is very slight, is to the southeast. A similar outcrop was found on the La Coste-Lytle road, 2 miles south of La Coste; and in the area between these two outcrops and Lytle the same rock was frequently observed on the surface in the sandy soil, which is the result of the disintegration of these sands.

At the Lytle mine, west of Lytle, the following section was observed:

	Ft
1. Brown sand, with boulders of sandstone, ...	10
2. Yellow laminated clay, with occasional clay and small boulders, ...	10
3. Laminated yellow-gray sand, with black clay or lignitic partings indurated in places, micaceous and very friable, . .	12
4. Brown coal, with lignite imbedded, ...	5 to 7
5. Gray clay, floor of mine.	

A well, which had just been dug a short distance south of the mine and on higher ground, passed through 60 ft. of the above materials, finding an abundance of water on top of the bed of brown coal. The water has a slightly sweetish taste.

For a mile south of Lytle the surface shows the micaceous sands (No. 1 of above section), with gray quartzitic sandstone concretions, which pass upward into interbedded and interlaminated sandy clays and sands with ferruginous and calcareous laminæ.

From this point to Rossville, 10 miles, the Atascosa creek flows nearly along the line of the dip of these rocks, and the great number of exposures shown by its banks give the details

of structure and composition somewhat more fully than is usual in these Tertiary deposits.

The first exposure observed shows 10 ft. of interbedded clays and sands, in which the ferruginous seams are in places simply nodules and strings of ferruginous material, and at others widen out into a ferruginous sandstone. This is overlain by a bed of mottled clays, capped by ferruginous sandstone, from 6 to 8 in. thick, in which the ferruginous matter sometimes exceeds the siliceous and forms a lean iron-ore. The beds above this are interlaminated clays and sands, with seams of siliceous limestone and quartzitic sandstone, from 2 to 6 in. thick, ferruginous laminæ also being present. The concretionary sandstones in one locality presented a queer phase, simulating huge barrel-heads cemented together, one on top of the other. A considerable amount of silicified wood was observed here, and, though not seen in place, it was in all probability derived from these beds. Further down the creek, or higher up in these beds, the siliceous limestones are much heavier, forming beds from 4 to 9 in. thick, and are quarried for local use. These beds of sandstone and limestone are, however, nothing more nor less than segregations and indurations of the sand-beds in which they occur, as can be readily seen at many localities along the creek. Similar sands and sandstones occur along the section to Benton, in banks, from 10 to 15 ft high, of interbedded sandy clays, with their siliceous limestones in lenticular masses, boulders and seams. The clays and sands are bright-yellow, red and black in color, micaceous, cross-bedded in places, and abound in cone-in-cone structure,—one stratum, 18 in. thick, having been observed.

One mile below Benton the interbedded sands and clays contain segregations of ferruginous sandstone, in the form of kettle-bottoms, in considerable numbers. The sands are cross-bedded, and show grainings of ferruginous stripes.

The following section was seen 1.5 miles below Benton:

	Ft.
1. Mottled, sandy clay, with seams and pockets of gravel (mostly ferruginous), ...	10
2. Red sand, ferruginous, with gravel, passing in places into ferruginous sandstone. Gravel mostly ferruginous; the rest in form of small, siliceous pebbles, ...	3
Unconformity.	
3. Chocolate clays and sands, weathering white to yellow. Ferruginous segregations and laminæ, ...	5

		Ft.
4.	Siliceous limestone, micaceous, shaly to flaggy, ...	3
5.	Chocolate clays, with efflorescence of sulphur, ...	6

Further down the creek the chocolate clays and sands (No. 3) are from 10 to 15 ft. thick, and are succeeded by interbedded brown sands and gray clays from 2 to 6 in. thick. These, in turn, are followed by 12 ft. of brown sand-rock, evenly bedded, passing at top into a shaly, ferruginous sandstone. Above this the interbedded brown sands and gray clays again appear, passing locally into heavy-bedded, siliceous limestone, which is of much finer grain than that above Benton. The rock-materials seen for some distance below this point are composed principally of interbedded yellow and white sandy clays, overlain by the beds we have called the Carrizo sands, composed of yellow and white sand-rock, and white sands, with ferruginous laminæ, of which from 25 to 30 ft. were seen in single exposures. This yellow (or pink) and white sand passes into mottled sand, somewhat argillaceous in places. This becomes strongly indurated and, where the sand is coarser, forms a grit, with clay-inclusions. Frequently these clay-pebbles are of pure white kaolin, which weather out and appear in quantity in the creek-bed. The sands are micaceous, contain fossil wood, and show ferruginous concretions in places, while at others, through more perfect dissemination of the iron, brown sandstone is found. At one locality a thin seam of ferruginous matter, widened out into a considerable pocket of clay or ochre of a light vermilion color.

For a considerable distance these sands present flexure after flexure, which, although not large, are sufficient to cause an unconformity between them and the overlying brown sands of the Marine beds. These beds correspond, both lithologically and stratigraphically, with the Queen City beds of east Texas, as described by Kennedy, and with the Carrizo sands of Owen, and are made the top of the Lignitic stage. They finally pass below the iron brown sands of the Marine beds, a short distance northwest of Rossville, giving the Lignitic series an extreme width along the line of dip of about 12 miles. The outcrop along this section has an elevation of from 625 to 775 ft. above sea-level.

All the beds are undulating, synclines and anticlines being numerous throughout the entire section. Local unconformities

between different parts of the beds were observed, and the whole aspect is that of very shallow water-deposits. In places the brown or buff sandstone also contains pebbles of pure white kaolin, as mentioned above. The sands become more clayey toward Rossville, and at that place are covered by a series of lignitic beds, seams of lignite, gray sands, with lignitic matter, chocolate clays, etc., which have the general character of the beds of the Marine stage.

International and Great Northern Sections.—Along the line of the I. and G. N. railway the lignitic beds may be seen in the cuts, creek and river banks, and in wells from the Medina river nearly to Pearsall. The Cretaceous-Tertiary contact probably crosses the Medina river near the railroad-bridge, since the west bank of that river shows the yellow boulders of siliceous limestone imbedded in gray sandstone, such as occur west of La Coste on the Southern Pacific. Four miles southwest of the river a well-dump shows the gray micaceous sands, and beyond this the lignitic clays, followed by gray sands with siliceous limestone, interbedded sands and clays, chocolate clays, brown sandstone and red and white sand, appear in regular order, although often covered by Reynosa or later materials.

Leona Sections.—On the Leona river, outcrops of these beds were found from a point 8 miles south of Uvalde to Batesville. The greater part of the area is covered by Reynosa and later deposits, and the only exposures seen were widely separated. The line of gravel-covered hills south of Fort Inge probably marks the position of the lowest Tertiary sandstone. South of that line wells show the presence of the gray laminated micaceous sands, and such outcrops as we could find along the river below the latter deposits would give the following section, beginning at base:

Yellow micaceous sandstone, with ferruginous nodules. This forms a hard bed of sandstone where we saw it, and contains considerable mica.

Chocolate clays and sands, with concretions of yellow limestone, irregular in shape, and from 1 to 4 ft. in diameter.

Yellow sands, with similar concretions. Some of these contain iron carbonate centers, and the exteriors are often ferruginous.

Brown and yellow sands, with inclusions of clay pebbles. This bed of sands carries some ferruginous laminæ, nodules and stringers. In many places it is a conglomerate of clay pebbles and sand, the clay being of a light-greenish color,

and the sands often ferruginated and indurated to a hard rock. From all that we could learn, these yellow sands continue southwest from Batesville to Loma Vista. We observed them in the divide between the Leona and the Nueces.

Nueces Sections.—The Nueces has cut more deeply into the deposits than has the Leona, and while in many places its banks show nothing beyond its own silts, there are a few good exposures between the ford on the wagon-road between Eagle Pass and Batesville and the town of Carrizo Springs. Along the road on the west side of the river, yellow sandstones, similar to those last mentioned, are seen cropping out in several places. In the breaks around the Dolores ranch-house the following section was made:

1. Brown and yellow sands, with clay pebbles.
2. Yellow calcareo-argillaceous sands, shaly to massive, with septaria, ferruginous nodules, etc.
3. Chocolate clays and sands, with limestone and iron segregations.
4. Yellow sandstone, similar to that of the Leona section.
5. Interbedded and interlaminated clays and sands, with seams of impure lignite. Iron pyrites, and the gypsum and sulphur derived from it, are abundant. Ferruginated wood also appears in these beds.

About 6 miles north of Carrizo Springs we find the last exposure of these yellow sands, with septaria capped by a fine-grained calcareous sandstone. From here we pass over a narrow strip of black land (Reynosa?) and then over sand-flats and gravel-ridges to the springs.

The Carrizo sands were first described by Owen in the *First Report of Progress of the Geological Survey of Texas*, and are the stratigraphical equivalent of the Queen City beds of Kennedy. They comprise interbedded sands and sandy clays, white or yellow in color, containing ferruginous matter as nodules, strings of concretions and laminæ. Pyrites is also found. The sands are somewhat calcareous, and are indurated in places to a buff sandstone excellently adapted for building purposes.

The court-house and jail at Carrizo Springs are built of this sandstone, quarried a short distance from the town. The sands are in places overlain by the Reynosa limestone, and the lime for these buildings was made by burning the material gotten from the deposit.

Mr. Owen states that these sands occur on the Nueces river

a few miles south of Uvalde, and extend southward. They are found as far as 10 miles west of Carrizo Springs, and are well exposed at the Nueces river, 8 miles or more east of Carrizo Springs, on the road between that town and Cotulla. This unusual width of exposure for these beds is caused by the erosion of the Nueces basin.

Rio Grande Sections.—The first exposure of the Lignitic beds observed on the Rio Grande was about 2 miles south of Webb Bluff. Here, on the Mexican side of the river, there is a bluff a quarter of a mile long and 75 ft. high, of interlaminated gray sands and chocolate clays, with sulphur and gypsum in places, and occasional ferruginous spots. Hard gray-clay ironstone with leaf-impressions are also found. The sand-beds are from 1 to 5 ft. thick, and show much cross-bedding. The clay is in thin laminæ. The dip undulates from 1 to 5 degrees southeast.

Along the face of the bluffs numerous faults were seen, but the dislocations were small.

For several miles below this point the exposures were all of similar character, but before reaching San Ambrosio creek we found the interbedded and interlaminated clays and sands capped by sands, which were heavy-bedded, cross-bedded, and carried ferruginous and calcareous concretions 10 or 12 ft. in diameter. Near the mouth of San Ambrosio creek the clays were succeeded by these heavy-bedded yellow sands, which are part of the Carrizo sands. From the San Ambrosio to the Jardin, and about 2 miles below, numerous low bluffs were found which showed 15 ft. or more of this massive sand without sign of stratification. Below this, however, the sand began to show bedding and some lamination, forming bluffs from 35 to 60 ft. high. After passing San Lorenzo creek the sands became somewhat calcareous and contained concretionary masses of limy sand. This is succeeded, near Espada creek, by beds which are ripple-marked and carry iron concretions, and these mark the culmination of this stage in this area. A mile below this point the Marine beds form the surface-rocks, and below that point the Carrizo sands are only occasionally exposed, as the undulating dip brings them to view below the more clayey Marine deposits.

The differences noted between the Lignitic of this section

and of those further east are its greatly increased sandiness, and the fact that we saw no exposures of beds of lignite in it at all. Our trip was a hurried one and we could only land at certain points, so that some of these may have been overlooked; but had there been such beds as occur in the east Texas section they would have been too prominent a feature in the topography to have been entirely overlooked. The importance of the sand-beds as a source of water, however, will probably compensate for the absence of the lignite in this western region.

In *Bulletin, U. S. G. S.*, No. 164, "Reconnaissance in the Rio Grande Coal-Fields of Texas," Mr. T. Wayland Vaughan has recorded his observations on a part of the area here described. On page 35 he says:

"*The principal result of the writer's work on the Rio Grande was in proving the existence of Eocene fossils some* 3 *or* 4 *miles above the Webb-Maverick county line*, 6 *or* 7 *miles above where Penrose and Dumble first found such fossils.*"

On page 38 he places the Webb-Maverick county-line about 3.5 miles above the mouth of San Ambrosio creek, on the authority of a colored cowboy, who told him that it was about a mile south of the south-line fence of the India ranch. His most northern locality, "1.5 to 2 miles above the fence referred to," would, therefore, be about 6.5 miles above the mouth of San Ambrosio creek. According to the map accompanying his report (Pl. 1), the county-line reaches the river at a point 9 miles above the mouth of San Ambrosio creek, and this agrees with our maps and with the facts. As Webb Bluff is only 3 miles by river below the county-line (which would not be more than 2.5 miles in a direct line), it is probable that his locality and ours are very close together. According to my notes the county-line is just below the falls of the Rio Grande, and our Webb Bluff is 3 miles below these falls. On my field-map it is noted at about 7 miles above San Ambrosio creek.

The principal result of his work, and one which I think much more important than such an extension of a boundary would be, was in finding Midwayan fossils directly below the Carrizo sands, and in beds which, on account of their lithological character, I have here described as Lignitic.

My report was written before I received Mr. Vaughan's paper. I have left it as I originally wrote it, although, after read-

ing his report and his description of the Myrick formation in the Uvalde folio of the *Geologic Atlas of the U. S.*, it seems to me that he has practically demonstrated the fact that the lower or lignite-bearing portion of the Lignitic, as we know it further east in Texas, is not exposed here, but that we have, instead, a phase of the Midway or Basal stage much more sandy than usual in character and carrying beds of lignite. The only other explanation possible, in the light of his facts, would be that some of the molluscan forms which elsewhere characterize the Midway had here persisted into the Lignitic. In this case there would probably be no exposure of the Midway or Basal beds in this region, but a Lignitic overlap, in which the upper beds of that stage (the Carrizo sands) also overlap the lower or lignite-bearing beds.

In any event it appears that we have ample proof of a great overlap by the Carrizo sands, since they have been observed to rest upon different horizons of the underlying beds. Thus Vaughan states,* "The contact [between the Cretaceous and the Eocene] is 9 miles east of the Robert Thompson ranch, where the Upper Cretaceous clays and the sandstones of the Carrizo Springs type are first initiated." The lithological character of the beds (*op. cit.*, p. 31) is certainly that of the Carrizo sands, which at other places rest upon various beds of the Lignitic or Midway.

His work seems also to emphasize a fact I have before noted, which is the increased sandiness of the Eocene, as a whole, on the Rio Grande, as compared with its typical character as shown along the Brazos.

Harris† suggests that it is quite probable that in this region the Lower Claiborne overlaps the Lignitic and Midway stages and meets the Cretaceous. He is mistaken only in the extent of the overlap, which, so far as we have seen, does not reach across the Carrizo sands. My notes, however, show that certain sands of the Marine beds extend beyond the exposed edges of the clays of that substage on to the Carrizo sands. It is to such overlaps as these that much of the confusion which has existed in this region is due.

Lower Claiborne Stage.—Owing to the great thickness of the

* *Bul.*, 164, p. 35.

† *Bul. Am. Paleontology*, No. 9, p. 7.

deposits which we must refer to this stage on account of their fossils, we have subdivided them into four sub-stages, partly on their lithological characters, although, as will be seen, each has, also, its own distinguishing paleontological characteristics. These sub-stages are, the Marine Beds, the Yegua Clays, the Fayette Sands and the Frio Clays, and these will be described, separately, below.

Marine Beds.—This series, which is predominatingly sandy, is composed of quartz-sand, with considerable amounts of greensand or glauconite and some clay and iron oxide. It is the principal fossil-bearing bed of the division, and the fossils evidence the fact that during the period of their deposition somewhat deeper water prevailed, and that the beds were laid down in seas or bodies of salt water.

Atascosa Sections.—The lowest bed of this section is a brown sandstone, and it is capped by white clayey sand, which gradually gives place to an arenaceous clay, with strata of sand. The light color is principally due to weathering, as both clays and sands are brown or black when freshly opened. The sandy clay is overlain at Rossville by the following section:

	Ft
1 Soil, passing downward into No. 2.	
2. Mottled sandy clay. Rests uncomformably on No. 3.	
3. Light-gray, massive sand-rock, ...	3
4. Interbedded chocolate clays and sands, coated with sulphur, and gray sands, with iron pyrites, ...	10
5. Brown coal, to water, base not seen, ...	2

Down the creek we find overlying No. 3 of this section a gray carbonaceous sand of more recent deposition, which encloses a peat-bed at one locality, and is overlain by sandy clay.

At Rossville, the creek turns southwest, practically following the strike of the rocks; and even after it makes its turn southeastward, and finally works its way back to its original direction, the exposures are few and unsatisfactory.

The general section may be given thus:

1. Soil, brown sandy or chocolate loam, as the sands or clays form the subsoil.
2. Interbedded brown (ferruginous) sand-rock and limy sands. In places the iron is more abundant, forming a lean iron-ore or a ferruginous sandstone. This sandstone forms ledges of sufficient hardness and extent to be used for building-purposes, and is quarried in a small way.
3. Clays and sandy clays with sand, weathering white or yellow.

The Atascosa creek, 4 miles northeast of Pleasanton, in numerous exposures, shows the same sand and limy sand. Plant-impressions were seen in some of the light-gray sands.

From the crossing of the Atascosa on the Rossville-Pleasanton road we pass over a high rolling country, with numerous exposures of heavy ferruginous conglomerate, consisting of siliceous and ferruginous pebbles in a ferruginous matrix, underlain by brown sandstones and grits.

Near Pleasanton, the brown sandstone is quarried for building-purposes. The court-house is built of it, and it has also been extensively used in the town. The different shades of brown admit of combinations which are very pleasing.

Bonita creek, which flows into the Atascosa near Pleasanton, furnishes the first bed of fossils found in the Atascosa section; and these, so far as observed by us, occur at one place only, three-quarters of a mile above the bridge on the Tilden road. The banks of this creek are, for the most part, composed of Pleistocene materials, with occasional exposures of the laminated clays and sands of the Marine beds. The fossils occur here in a bank of brown, sandy clay from 6 to 7 ft. thick. This is divided into two portions by a seam of concretionary limestone, which is also fossiliferous. The base, which is more fossiliferous than the upper portion, rests on black gypseous clays. The fossils found were:

Venericardia planicosta, Lam.; *Dentalium multistriatum*, Gabb; *Pseudoliva vetusta*, Con.; *Cerithium texanum*, Heilp.; *Barbatia cuculloides*, Con.; *Mesalia claibornensis*, Har.; *Ostrea divaricata*, Lea; and are all forms belonging to the Lower Claiborne. South of Pleasanton the same laminated clays and sand, with gypsum, limestone concretions and fossils, are found for 8 miles, when they are covered by the dark clays and white sands of the Yegua.

International and Great Northern Railroad Sections.—Beginning just north of Pearsall, on the above railroad, the deposits belonging to the Marine beds are exposed in numerous places along the line all the way to Laredo. In many places they are overlain by the Yegua clays, the Reynosa or other materials of later date; but wherever these are cut through by erosion, the beds of this division make their appearance. Fossils occur in them at many places along the line.

In La Salle and Dimmit counties, between Cotulla and Carrizo Springs, we found the upper brown sandstones of these beds, with their characteristic fossils, outcropping along the road for about 6 miles after leaving Cotulla. Beyond that point the underlying beds furnish no exposures of any consequence until we reach the bridge over the Nueces river, where the Carrizo sands begin.

Frio County Sections.—From Pearsall, southeast toward Tilden, exposures of these deposits are found extending nearly, or quite, to the southeast corner of Frio county, but a large portion of the area is covered by deposits of later date; and as the surface is only gently rolling, with few breaks or excavations that pass through these, few really good exposures were found. Such well-sections as could be secured showed the presence of the brown sands, underlain by the white and yellow sand, and these by the carbonaceous clays and lignite, as in the Atascosa section. In the well at the ranch of Mr. J. O. Handy, near the Atascosa county-line, these brown sands, with an enclosed gravel-bed, were 235 ft. thick. To the southeast they are overlain by the more fossiliferous portion of the beds, which are well exposed in the breaks of the San Miguel and Mustang creeks, and by numerous well-sections in the neighborhood.

About 12 miles south of Pearsall a hard, brown sandstone (altered greensand) crops out in the Pearsall-Tilden road, and contains numerous fossils similar to those found in the beds at Pleasanton.

The following section was made of a well which was being dug on the Arnold ranch, 14 miles southeast of Pearsall:

	Ft.
1. Soil and subsoil, ...	3
2. Clay and gravel, ...	9
3. Brown sand, ...	10
4. Altered greensand, fossiliferous, ...	2
5. Laminated lignitic clays, soapstone of well-diggers, ...	23
6. Greensand, fossiliferous and containing fragments of lignite, .	1
Conus sauridens, Con.; *Pleurotoma terebriformis*, Mk.; *P. nodocarinata*, Gabb; *Pseudoliva vetusta, var. clausa*, Har.; *Volutilithes precursor*, Dall; *Latirus moorei*, Gabb; *Corbula alabamiensis*, Lea; *Venericardia planicosta*, Lam.; *Cytherea bastropensis*, Har.; *Neptuna enterogramma*, Gabb; *Trigonarca pulchra*, Gabb; *Turbinella, sp.*	

One and one-half miles east of this ranch the hills are capped with a brown sandstone, or altered greensand, full of *Anomia* shells, with *Modiola texana*, Gabb.

San Miguel creek, below the DeVilbiss ranch, gives the following section:

		Ft.
1.	Black soil, with brown subsoil, ...	8
2.	Conglomerate of flint gravel, containing occasional large brown sandstone boulders, ...	0 to 2
3.	Altered greensand, full of large oysters, ...	0.5
	In some places this was replaced by yellow, sandy clay, from which the oyster-shells could be removed without breaking.	
4.	Thinly laminated, bright, yellow-brown sand, with reed-like casts traversing it in all directions, ...	6
	Two-thirds of a mile north and underlying this we find,	
5.	Thin-bedded brown sandstone, ...	2
6.	Altered greensand, very hard, ...	1
	Pleurotoma (*Surcula*) *gabbi*, Con.; *Levifusus trabeatus*, Con., var. Har.; *Conus sauridens*, Con.; *Pseudoliva vetusta*, var. *clausa*, Har.; *Volutilithes petrosus*, Con.; *Cornulina amigera*, Con.; *Corbula alabamiensis*, Lea; *Venericardia planicosta*, Lam.; *Cytherea*, *sp.*; *Sigaretus declivus*, Con.; *Turritella nasuta*, Gabb; *Chrysodomus enterogramma*, Gabb; *Nassa texana*, Gabb; *Ostrea contracta*, var. *frionis*, Har.; *Leda opulenta*, Con.	
7.	Laminated brown sand, ...	1

Rio Grande Sections.—The lithological distinction between the various subdivisions of the Lower Claiborne are not so distinct on the Rio Grande as they are further east. In place of the characteristic alternations of a series of sand-deposits succeeded by one of clays, we have here a series of shallow-water, near-shore deposits, with recurring oyster-reefs, which are so like each other as to form only a slight basis for separation. The course of the river is also more nearly on the strike of the beds, and the detached exposures and frequent reversals of dip make it very difficult to arrive at satisfactory determinations.

A mile below Espada creek, and about 8 or 9 miles above Palafox, a line of hills approaches the river. These are composed of greenish clays and lignitic sands, carrying palmetto leaves and other fossil-plants. These hills are much better wooded than those passed above. The first section showed:

		Ft.
1.	Siliceous sand colored red, yellow and purple in seams, . . .	40
2.	Light-green clay, with mica. Plant-remains, ...	10

From here similar strata are seen on both sides of the river until we reach the San Tomas coal-mines. A generalized section of the beds in this vicinity would be:

	Ft.
1. Calcareous sands,	12
2. Friable sandstone,	12
3. Interbedded chocolate, gray, white and brown sandy clays, with sulphur and gypsum in seams, and passing downward into black clays with 2-in. seam of woody lignite,	10
4. San Tomas coal-seam—2-in. clay-parting,	2.5
5. Gray-clays with lignite,	10
6. Interbedded sands and clays,	75
7. San Pedro coal-bed,	2.5

In the sandy clays of No. 3, we found a thin seam of limy sand which carried a number of fossils, comprising oyster and *anomia* shells, bones of turtle, shark-teeth, etc., but all so decomposed that we could not identify them.

About 35 ft. above the San Pedro bed there is a band of shell-breccia, which contains a great number of fossils. Among these were: *Ostrea divaricata*, Lea; *Anomia ephippioides*, Gabb; *Corbula texana*, Gabb, and many others.

Below this point we find the indurated, concretionary clay and sand of greenish color, and containing fragments of vegetal matter, forming the banks of the river. At places, these show the characteristic weathering of carbonaceous clays—green, chocolate and purple colors.

The exposures on the Mexican side, near the mouth of Escondido creek, while closely resembling those above, are composed of much coarser sand, with crystals of gypsum, particles of lignite, etc. These sands are cross-bedded in places, and form the river-bluff on the Mexican side for some distance. Similar materials, giving bluffs of greenish appearance, spotted in places by ferruginous matter and marked by concretions and "cannon-balls," reach to within 9 miles of Laredo. A mile below this exposure, these give place to the buff sandstone, which is the surface-rock over so large an area in the Nueces valley, and which here forms long lines of bluffs, 40 ft. or more in height. Between this point and Laredo we observe that the buff or brown sandstone shows its green color at the water's edge, and that it is interbedded with materials similar to those which underlie it further up the river.

The Lower Claiborne age of the deposits around Laredo has been shown by several observers.

At the mouth of the Chacun, just below Laredo, we found these beds, but more calcareous in composition, interbedded with chocolate clays. They were overlain by interbedded greensands and chocolate clays. The greensands contained many casts of *Turritella* and *Cardita*, and numerous shark-teeth, and was overlain by an oyster-breccia (*O. alabamiensis*, Lea).

Strata of sandy conglomerate, with many black pebbles and fish-remains, were interbedded with the sandy oyster-breccia, and, as the dip brought these beds to water-level, the edges of the beds gave rise to a series of rapids. Beyond this, bluffs of bedded brown sandstone appeared, in which we found no fossils. As we now understand it, these mark the top of the Marine beds in this region, although it is acknowledged to be merely an arbitrary division, based on the occurrence of Yegua fossils near the top of the next section observed, which was some 10 miles below Laredo.

Yegua Clays.—The beds of this division, in this region, comprise a series of interbedded and interlaminated sands and clays, with massive beds of sand, seams of plastic clays and kaolins, and heavy beds of brown coal.

The clays are usually dark-blue, weathering to a dirty-yellow, with a profusion of crystals of gypsum. In places they are massive, at others laminated. The sands are gray and white, often laminated or cross-bedded, but sometimes massive. The fossil-wood is silicified, and not opalized, as in the succeeding Fayette beds.

The fossils found in them show them to be of Lower Claiborne age.

Atascosa Creek Sections.—The basal-beds of the Yegua clays, as seen in the Atascosa creek section, are laminated, calcareous clays, of a greenish-gray color, overlain by a bed of cone-in-cone material. An exposure on Atascosa creek, at McCoy's ranch, gave the following section:

	Ft.
1. Gray, sandy soil, ...	5
2. Mottled, clayey sand, ...	5
3. Gray joint-clay, laminated, ...	4

	Ft.
4. Laminated to massive sands and sandy clays, weathering red and purplish, some sulphur and fragmentary fossils (*Turritella* and *Crassatella*),	8
5. Gray clay, almost a kaolin in places, with calcareous boulders in others,	5
6. Seam of limestone boulders,	0.5
7. Gray joint-clay, with stains of manganese and ferruginous seams,	6

Other exposures below this show similar clays for 2 or 3 miles, and on the Crain survey we found the following:

	Ft.
1. Brownish-gray, sandy soil, passing into	
2. Red-brown, micaceous, clayey sand, containing ferruginous and siliceous pebbles and silicified wood,	3
Unconformably on	
3. Light-brown, sandy clay, with manganese markings and calcareous strings and concretions, passing downward into interbedded and interlaminated gray and yellow clays, with seams of white, limy clays and sand, locally indurated,	3 to 6
Uncomformably on	
4. Interbedded and interlaminated gray sands and chocolate clays, with ferruginous seams, The sands are strongly cross-bedded in places, and contain pockets of gravel and clay pebbles.	11
5. Interbedded and interlaminated light-gray and chocolate sands and clays, with lime, containing great boulders and masses of cone-in-cone concretions through it; sulphur, abundant. In places, this bed weathers to a purplish color, and has seams of white clay parting it. Toward the base it is more clayey,	7

The hills at ranch-house of Mr. Peeler gave the following section:

	Ft.
1. Reynosa covered.	
Fayette?	
2. Yellow clay, with great numbers of geodes of aragonite, the centers of which are lined with chalcedony,	4
3. Yellow sands, becoming brown and rusty toward bottom,	3
4. Aragonite,	0.5
5. Interbedded sands and clays. Clays kaolinic in appearance, but passing into sandy clays in places; sands frequently laminated, and, just below the aragonite, flaggy in structure. A fossiliferous band was found in these, but fossils were poorly preserved. *Cerithium pliciferum*, Heilp. was the only form determined,	40
Yegua?	
6. Laminated clays, with claystone,	2
7. Greenish-gray clay, with some sand-laminæ,	6
8. Lignitic clays and sands,	3

The interbedded sands and clays (No. 5 of section) are quite irregular, as shown by their outcrops in the hillsides, and the fossils obtained from them prove them to belong to the Fayette beds. They are probably the base of that substage in this vicinity. Some of the clays are white and free from sand, and some of the sands are laminated. Other strata consist of sandy clay and clayey sand. Toward the upper portion of the hill the aragonite, which at other places has occurred in the form of great boulders of cone-in-cone, assumes a place in the stratified materials as a regular bed.

The upper bed of sandy clay (No. 2), with geodes of aragonite, the centers of which are lined with chalcedony, is the only occurrence of the kind I have noticed in the Texas Tertiary. The geodes are round, from 6 to 18 in. in diameter and from 4 to 8 in. thick. They are quite numerous on the hill; but many, if not most, we found to be broken.

Mr. Peeler has bored several wells on his place and furnishes the following statement of the materials passed through, giving in the single section the general succession of the beds of this division:

	Ft.
Fayette?	
1. Soil.	
2. Interbedded sands and clays,	40
3. Gray marl,	45
Yegua?	
4. Brown coal,	19
5. Shale,	12
6. Joint clay,	33
7. Clay,	27
8. Gray sand,	35
9. Blue siliceous limestone,	1.5
10. Blue joint-clay,	15
11. Clay,	7
12. Coarse, gray sand,	12
13. Interbedded sands and clays; gray, water-bearing sand at base,	48
14. Interbedded sands and clays with kaolin bed. Gray, water-bearing sand at base,	100
15. Interbedded sands and clays,	160
Total,	554.5

Calculating the dip on a basis of 50 ft. per mile, the bottom of this well has nearly, or quite, reached the base of the Yegua clays. The water was rather salty and sulphurous, with the

exception of the flow of water encountered at 400 ft., which was fresh and rose to within 75 ft. of the surface.

The bed of brown coal crops out in places north and west of Mr. Peeler's, but was covered along our immediate line of sections.

Similar beds were also exposed on Lipan creek, south of Campbellton, where the following section was made:

	Ft.
1. Gray, sandy soil,	1 to 4
2. Dark-gray, clayey sand, mottled toward base,	4
3. Brown sand with black specks, with gravel of silicified wood, siliceous pebbles and clay,	6 to 8
Unconformably on	
4. Brown, sandy clay, with gypsum passing downward into gray sands with cannon-ball concretions,	4

At another locality, No. 3 of above section appears as a yellow, sandy clay stratified with seams of calcareous and kaolinic materials, heavy beds of gravel in a coarse sand-matrix—pebbles and boulders of sandstone, limestone, ferruginated and silicified wood, and also of the underlying clay. Traced to the east this bed again passes into brown sand. It belongs to the Tertiary, but is possibly Oakville, or later.

No. 4 is present at the same locality as light, greenish-gray clays, with immense quantites of concretions and geodes, containing crystals of quartz 0.5 in. and larger in their centers. Some of the concretions are perfectly round, the "cannon-ball" of the Mexican Boundary Survey, and others septarial, the septa being calcite, yellow, purple and chocolate in color. These clays are rusted in places, but are not jointed or sandy. The greenish clays, with concretions, are the highest bed of the Yegua clays, and they also appear in one of the higher hills, 2 miles south of the Peeler ranch-house, where they are capped with the Fayette sandstone. This hill is a mile and a half northwest of the Lipan creek section, and has an elevation of 120 ft. above that point.

Tilden Sections.—From Arnold's ranch, on the Pearsall-Tilden road, the clays of this division show few exposures, but well-sections and the scattered outcrops show that greenish clays, with lime, prevail as far south as Tilden.

At Turtle Lake the outcrops show:

	Ft.
1. Soil,	2
2. Gravel,	3
3. Brown, yellow and gray laminated sands, with gypsum,	12
4. Greenish, laminated clay,	1
5. Laminated, brown and gray sands, with gypsum in the laminæ,	3
6. Laminated, greenish gypseous clays,	5

All of the sands and clays of this section contain nodules of kaolin.

The right bank of Leoncita creek, three-quarters of a mile above the crossing of the Tilden and Pearsall road, shows:

	Ft.
1. Soil, underlaid by siliceous gravel,	3
2. Greenish clay, exposed,	2
3. Interbedded and interlaminated gray and brown sand and lignitic shales, with leaf-impressions,	3
4. Impure, brown, clayey lignite, with small lenticular beds of gray sand and fragments of silicified wood,	3
5. Laminated, gray and yellow sand,	5

The entire bed is more or less coated with sulphur.

The exposures on Bill Walker branch of Leoncita creek show the same character of clays, capped by sandy clays, laminated sand and sandstone. Many fragments of silicified and opalized wood were found here, probably derived from the clays, or left by the erosion of the Fayette sands from above them.

On Leoncita creek, 3 miles northwest of Tilden, the following section was obtained:

	Ft.
1. Soil.	
2. Greenish, laminated clay,	17
3. Brown sandstone, indurated on top, calcareous at base, full of oyster-fragments,	3
4. Greenish, limy clay (to creek-bed),	2

International and Great Northern Sections.—On the above-mentioned railroad these clays may be seen near Webb station, and at other places between that point and Laredo, overlying the brown sands of the Marine beds.

Ten miles east of Laredo, on the line of the Mexican National railroad, the same clays occur, and are exposed at intervals for 2 or 3 miles.

Rio Grande Sections.—Ten miles south of Laredo, and about the same distance, by river, above the Webb-Zapata county-line,

we find the first deposits which, from their fossil-contents, we can, with certainty, refer to the Yegua clays. This is a bluff, nearly a mile in length, on the Texas side of the river. Here are exposed a series of interbedded greensands, brown sand and chocolate clay, with lenticular masses of a red sandstone. Near the top of the hill there is a bed of altered greensand containing quantities of fossils, among which Mr. Harris determined: *Lucina alveata*, Con.; *Natica recurva* var. *dumblei*, Heilp.; *Cerithium sp.*, *C. webbi* Har.; *Anomia ephippioides*, Gabb; *Ostrea alabamiensis*, Lea; *Cornulina armigera*, Con.

The round concretionary masses, called cannon-balls, are abundant, both in the bed of greensand and in the red sandstone. The chocolate, sandy clays are cross-bedded.

A mile below this, a bluff on the Mexican side shows more clearly the characteristically clayey nature of the Yegua. This bluff is nearly 2 miles in length, and is composed of indurated blue or gray clay, interbedded with altered greensand and gray-brown sands. It contains a thin bed and seams of lignite. Beyond this, a bluff, 75 ft. high, shows the chocolate sands and clays, highly variegated in color,—purple, red, pink, yellow and brown,—and capped by a brown sandstone which weathers black in places. Considerable amounts of iron pyrites and gypsum are present.

About the line of Webb and Zapata counties there is a bluff from 60 to 100 ft. high, and at least half a mile long. The beds are nearly horizontal, as seen from the river, which here flows east. The base of the hill shows a band of buff and greenish sands, slightly calcareous, with large concretions from 8 to 10 ft. in diameter. This is overlain by an extremely hard, limy band of grayish color, which shows on its upper surface a breccia of a very large gasteropod.

Overlying this is a series of sand of varied colors and a second limestone layer, very rich in fossils, including such forms as *Conus sauridens*, Con.; *Ostrea alabamiensis*, Lea; *O. divaricata*, Lea; *Volutilithes petrosus*, Con.; *V. petrosus* var. *indenta*, Con.; *Tellina mooriana*, Gabb; *Corbula alabamiensis*, Lea; *Cytherea texacola*, Heilp.; *Natica recurva* var. *dumblei*, Heil.; *Turritella nasuta* var. *houstonia*, Har.; *Venericardia planicosta*, Lam.

The next bluff, 2 miles below on Texas side, showed only brown sands, without fossils, for a height of 60 ft., but at the

mouth of Dolores creek we again find the greensands in hill 20 to 35 ft. high, with beds of oysters from bottom to top.

Four miles below this there is a low reef of hard, gray limestone, weathering to a greenish-gray color. It is concretionary in places. Four miles above San Ignacio there is a bluff 300 yards long and about 60 ft. high. Below the alluvial deposits it is composed of buff sands and sandstones, with seams of lignitic clays, sands and greensands.

At the top of the sandstone there is a fossil-stratum about 8 in. thick. This gave: *Pleurotoma nodicarinata*, Gabb (?); *Levifusus trabeatus*, Con., var.; *Tellina mooriana*, Gabb; *Corbula alabamiensis*, Lea; *Venericardia planicosta*, Lam.; *Cythera sp.; Natica recurva* var. *dumblei*, Heilp.; *Volutilithes petrosus*, Con.; *Ostrea alabamiensis*, Lea.

Gypsum and cannon-balls occur, as well as numerous white calcareous concretions. The "bombshells" contain traces of lignitic materials. The dip here is normal—S.E. Two miles below, a bluff on the Mexican side of the river, composed of the gray sandstones with calcareous concretions, shows a distinct northeast dip. The same sandstone, still dipping northeast, appears as a reef at San Ignacio. The exposures at the mouth of Salidita creek, about 2 miles below San Ignacio, show a bed of siliceous limestone, with beds of altered greensands. This is overlain by a buff sandstone which, in its next appearance, is seen to be cross-bedded and jointed.

Four miles below San Ignacio the river-bluff shows this same buff sandstone underlain by greensands. The buff sandstone is quite calcareous, carries gray nodules and shows concentric weathering.

A mile below this exposure the dip changes from northeast to northwest, and shows somewhat greater angles than is usual in these beds, amounting to as much as 10°. The materials exposed are semi-indurated sands, with more compact boulders of the same material. This is overlain by blue and green ferruginous clays, which weather a deep-red and show concentric weathering. White, calcareous concretions abound in this bed. Yellow, sandy clay, becoming more compact toward the top, succeeds the heavy clays. No gypsum was seen, and but little sulphur.

Two miles below, the dip again changes to southeast, and

the buff sandstone shows beds of flagstone, which are somewhat calcareous, and contain black, cherty grains. These beds continue to a point 4 miles north of Carrizo, where we find the contact of the clays of the Yegua with the Fayette sands.

Fayette Sands.—This name was originally used by Penrose* for the entire series of deposits between the top of the Marine beds and the base of the Coast clays. Investigation shows that this would embrace deposits of different ages, and the name is here used with restricted significance for that sub-division of the Tertiary to which it is most applicable. Some confusion has arisen from the fact that two somewhat similar beds of sands occur in the Texas area, separated by a band of clays of variable thickness, so that, at times, we may pass from one to the other without noticing the change. The lower of these sandstones is the *Fayette sands*, as here described, and is of Lower Claiborne age, while the upper, which will also be described in the following pages, under the name of *Oakville beds*, is shown by its fossils to belong to the Miocene. This differentiation was correctly made by Dr. Buckley† in 1874, but was overlooked by us.

The Fayette sands comprise a series of sands and sandstones with some clays, which contain a large amount of opaline and chalcedonic materials, lignitic clays and brown coal. The sands are usually coarse, angular to rounded in grain, forming sandstones of varying degrees of hardness, highly quartzitic in places and cemented by an opaline matrix at others.‡ Large quantities of opalized wood occur, and chalcedony is abundant, forming the centers of geodes, the septa of septaria, and even filling crevices in the sandstone.

Beds of volcanic dust and siliceous sinter also occur, interbedded with the clays and lignites. Many of the clays are white and of sufficient purity to be valuable for the manufacture of the finer grades of earthenware.

There is no very sharp line of demarcation between these beds and the underlying Yegua clays, but in this region, as further east, the Fayette sands make themselves known topo-

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* *First Ann. Rept. Geol. Survey of Texas.*

† *First Ann. Rept. Geol. and Agr. Survey of Texas*, p. 64.

‡ This is also true of the Oakville beds, and has been the principal reason for the reference of two entirely different sets of beds to one division.

graphically by a line of bluffs facing north or northwest. In this area the range of hills begins near Brackenridge or Falls City, on the San Antonio and Aransas Pass railroad, and runs southwest toward Tilden. Its invertebrate fossils are not very numerous, but mark it as belonging to the Lower Claiborne stage, and as the deposits of shallow waters.

Atascosa Sections.—The first appearance of these beds in this line of section was at Peeler's ranch, and has been described in connection with the Yegua beds, which there appear below it.

Two miles southeast of Campbellton we made the following section at the point of the ridge on the east side of Lipan creek. The top of the ridge was by barometer measurement 145 ft. above the creek, but much of the base of the hill was so covered with detritus that our section only includes the upper 80 ft. of it.

		Ft.
1.	Brown sandstone, with black specks and fragments of opalized wood. This occurs here only in remnantal boulders, the main deposit having been nearly removed by erosion.	
2.	Septarial sandstone. Red and white sand, very compact, heavy-bedded. The white is in lines and seams inclosing the red, thereby giving it the appearance of a great breccia. The red is softer and weathers out, leaving the white parting standing up from 0.5 in. to 6 in. When these white partings are close together, they resemble a mass of fucoids, ...	8
3.	Unevenly-bedded light-brown sandstone, rusted and streaked with ferruginous matter. Colors sometimes in bands, . .	10
4.	Quartzite, ...	2
5.	Sandstone, with a little clay, laminated to flaggy in structure, showing lines and grainings of white, yellow, gray, etc., . These beds contain fossiliferous bands. *Modiola texana*, Gabb ; *Corbula alabamiensis*, Lea ; *Mactra sp.* (?)	30
6.	White, shaly sandstone in fragments, ...	6 to 8
7.	Brown sandstone, ...	2
8.	White sands with opalized wood, ...	6
9.	Brown coal, ...	1
10.	Laminated sand and opalized wood, ...	10
11.	Lignitic clays and sands, with sulphur efflorescence (bottom not seen), ...	5

Frequent exposures of these same beds are seen as we follow these hills southeast. A second fossiliferous horizon was found above No. 3, of above section, and the contact of No. 5 and No. 6, which was covered at first locality, was found at another

near-by. The sandstones are unevenly bedded, firm, and have a square fracture. The fossils occur in them in nests. The underlying sandy shales are, as before, much broken, and of a whitish-yellow color.

The fossils taken at this locality were: *Levifusus trabeatus*, Con.; *Nucula magnifica*, Con.; *Cornulina armigera*, Con.; *Mactra*, *sp.* (?); *Corbula alabamiensis*, Lea; *Cytherea bastropensis*, Har.; *Turritella nasuta*, Gabb; *Corbula aldrichi*, var.; *Tellina scandula*, Con.; *Hiatula* (?); *Pseudoliva vetusta*, Con.

A bluff, 90 ft. in height, on the Atascosa, near Mr. Whitsett's house, gave the following section:

	Ft.
1. Gray sandstone, weathering yellow,	2
2. Sandstone, from 2 to 6 in. thick, interbedded with laminated sands in bands from 2 to 10 in. in thickness,	10
3. Cross-bedded brown sands, fossiliferous, laminated in places,	3
4. Interbedded and interlaminated clays and sands, weathering in light colors like Fayette materials elsewhere,	15
5. Light-brown sand-rock, with segregation of cone-in-cone,	6
6. Fossil-bed, with parting of gypsum-crystals,	3
7. Same as No. 5,	11
8. Lignitic clays and sands, with efflorescence of sulphur,	6
Detritus-covered to creek.	

The brown sands (No. 3 ?) cross the road from Oakville to Campbellton, about 6 miles from the latter place, and, at that point, contain numbers of large oysters (*Ostrea alabamiensis*, var. *contracta*, Con.), specimens of which were collected by Mr. Leverett.

Continuing down the Atascosa, these sands and sandy clays are found in numerous exposures.

Two miles southeast of the Atascosa county-line we found:

	Ft.
1. Black, sandy soil,	2
2. Mottled, red-brown, clayey sand,	3
3. Coarse, brown sand, with heavy gravel at base (all derived from materials of underlying beds),	3
4. Interbedded sands and clays of light colors, with manganese and rusty stains,	30

These beds being undisturbed in any way, and exposed for a long distance in the line of dip, furnished one of the most satisfactory of the observations we made for dip, which is here, by instrumental measurement, 50 ft. to the mile.

One mile below we have the following section:

	Ft.
1. Black soil, underlain by mottled sand,	4
2. Stratified sands, cross-bedded in places, with heavy gravel at base,	6 to 10
3. Greenish-gray joint clays, with manganese stains,	8
4. Laminated and bedded clays, with rusty bands, and containing two opalized stumps standing erect,	6
5. Sandy clays, with clay stones and ferruginous concretions,	4
6. Cross bedded, yellow sands,	6

One-half mile below the next higher beds appear:

	Ft.
1. Soil and subsoil, as before,	3
2. Yellow packsand, with logs of silicified wood,	15
3. Lignitic sands and clays, logs of fossil-wood, both silicified and opalized, numerous leaf-impressions in the shales,	10
4. Mottled, yellow clays at water's edge.	

This is the final appearance of these sands with fossil-wood in the line of sections, and is, therefore, made the upper limit of the Fayette sands.

Tilden Sections.—In the San Diego-Pearsall section the northern boundary of the Fayette sands was placed at Tilden. The beds form the divide between the Frio and Nueces, and there are many excellent exposures of them between the two rivers.

They find their culmination in the King hills, 2 miles north of the Nueces.

The brown sand is first exposed in the south bank of the Frio at Tilden, and well-sections show that it is underlain by the greenish-gray clays of the Yegua.

At Atkinson's ranch, 1.25 miles southwest of Tilden, we observed the following exposure:

	Ft.
1. Brown sandstone, laminated to bedded, containing fine leaf-impressions toward top. Inclosures of greenish clay,	27
2. Interbedded brown sands and clays, capped by a 3-ft. bed of greenish clay, with laminæ and pockets of calcareous material,	30
3. Interbedded and interlaminated greenish clay and clayey sands, with gypsum, lime and iron concretions. Exposed,	8

Number 3 becomes gray toward the top, and all surfaces are so coated with white, limy clay that the rock quarried from it closely resembles limestone.

One and one-half miles south of this, No. 1 of above section was overlain by a gray and brown, thinly-bedded sandstone, crossed by joints and breaking into flags. Above this

there is a bed of gypseous clay, weathering yellow to black, with an abundance of fossil-wood.

One-fourth mile south, this clay is overlain by brown, clayey sand full of sulphur.

A well-section, 2.5 miles south of Atkinson ranch-house, shows:

	Ft
1. Soil and subsoil, ...	7
2. White sandstone, limy and ferruginous, containing fossils (*Cerithium, sp.; Tellina mooriana? Solen, sp.*), gypsum and ferruginous concretions, ...	12

A hill-section south of this:

	Ft.
1. Brown sandstone, very hard at top and coated with white, limy clay. Beds from 12 to 18 in. thick. An oyster was found at the top of the beds, and Ceronia casts about 6 ft. below, . .	15
2. Thinly-bedded, brown and gray sands; near the top a greenish sand is interbedded with these, ...	20
3. Clay? (covered), ...	14
4. Laminated, reddish clay, seamed in all directions, with gypsum, sulphur efflorescence, ...	6

Two miles south of Tilden a deep branch exposes the following beds:

	In. Ft.
1. Gravel detritus from hill, gray and brown sand, and some flints, ...	1.5
2. Pinkish, lignitic shale, with leaf-impressions and large fragments of fossil-wood, ...	4
3. Gray, laminated sand, ...	7
4. Gray sand, full of crystalline gypsum laminæ, ...	0.25 to 4
5. Reddish, sandy clay, laminated and containing sulphur, and seams of selenite running through it in every direction, .	8

Four miles below Tilden, on the Tilden and San Diego road, a small creek shows an exposure of:

Brown sugary sandstone, hard at top, bedded, interlaminated in places with streaks of white, limy clay, base not indurated, 20 ft.

One-third mile beyond this the sand is overlain by a yellow, sandy clay, containing selenite, cone-in-cone and aragonite.

At Pace's ranch, 5 miles south of Tilden, the following well-section was obtained:

	Ft.
1. Black soil and subsoil, ...	6
2. Brown, flaggy sandstone, with white clay coating, ...	15

	Ft.
3. Yellow packsand,	17
4. Brown sandstone,	1
5. Yellow packsand (some gypsum),	11

The following section was made in the gap of the King Hills:

	Ft.
1. Brown sandstones, with plant-impressions,	8
2. Gray, calcareous sandstone, with honey-comb cavities, bedded at top, laminated at base,	10
3. Laminated, gray sandstone, fossiliferous at base,	15
4. Yellow clay, with selenite in large quantities and calcareous concretions,	10
5. Interbedded brown sand and sandy clay (detritus-covered),	17
6. Lignitic clay, with 2 ft. of shale at base, and containing leaf impressions,	6
7. Laminated, pinkish, clayey, shaly sand,	10
8. Yellow, laminated sand (soft) containing septaria, with septa of chalcedony, to creek-level,	4

Similar beds are found elsewhere along the section until the valley of the Nueces is reached, where the sands are overlain by the Frio clays.

Rio Grande Sections.—The first exposure of the Fayette beds in the Rio Grande region is described by Dr. Penrose as follows:

"Four miles above the Texas town of Carrizo, and on the Mexican side of the river, is seen a bed of woody lignite 1.5 to 2 ft. thick, overlain by 10 ft. of buff sands and underlain to the water's edge by 4 ft. of greenish-gray clay. The Rio Salado flows into the Rio Grande from the Mexican side opposite Carrizo. The town of Guerrero is on this river 6 miles from the mouth, and in this distance are seen many outcrops of buff sandstone, often rising in abrupt ledges through the river alluvium. Most of the houses, churches and fences of the town are built of it."

At Carrizo the beds yielded the following fossils: *Lucina alveata*, Con.; *Ostrea alabamiensis* var. *contracta*, Con.

Similar exposures are seen just below Carrizo, where the river runs more nearly in the strike of the beds. After it again turns southeast the buff sands form low bluffs for 2 or 3 miles, when we find, on the Mexican side of the river, in a long, low line of exposures, a greenish, sandy clay, partly indurated, but variable, with harder green concretions, which are more or less calcareous. Here we found: *Lucina alveata*, Con.; *Volutilithes petrosus*, Con.; *Cornulina armigera*, Con.; *Cytherea bas-*

tropensis, Har.; *Tellina mooriana*, Gabb. A similar exposure, just below, on American side, was a mile or more in length, and showed many undulations. This was in turn succeeded by exposures of buff sandstones, which here seem to dip about 6 degrees to the SE. This condition continues to the mouth of a small creek just north of Rancho Ramireno, which "cuts through a series of low bluffs, ledges of interstratified buff standstones containing gray concretions and septaria, and chocolate, black and greenish-blue semi-indurated clays, dipping from 1 to 2 degrees southeast."

The forms identified by Prof. Harris are: *Ostrea contracta*, Con.; *Conus sauridens*, Con.; *Volutilithes*, *sp.; Venericardia planicosta*, Lam.; *Semile lienosa*, Con.; *Cytherea bastropensis*, Har.; *Lucina alveata*, Con. var.; *Pseudoliva vetusta*, Con.; *Natica recurva.*

There is a fossiliferous layer near the mouth of the creek and forming its bed. This shows a mass of shells much comminuted. The few specimens which we found entire had, doubtless, weathered from the softer buff sands, as we found them in place in that material. These clays and sands are highly colored, and as usual show considerable cross-bedding. In the drift we found many beautiful agates, chalcedony and petrified wood—which here made its first appearance on our trip. The buff sands and interbedded materials formed a reef below the mouth of the creek and continued down the river several miles, when a bluff was found on the Mexican side which showed "interbedded hard and soft calcareous sandstones and clay seams," and contained *Volutilithes petrosus*, Con.; *Turritella, nasuta*, Gabb; *Lucina alveata*, Con.? *Anomia ephippioides*, Gabb; *Leda opulenta*, Con.; *Venericardia planicosta*, Lam.; *Tellina mooriana*, Gabb; *Cytherea bastropensis*, Har.

Numerous calcareous concretions are found, and the sand occasionlly contains coarse, black and gray siliceous grains the size of a mustard-seed and larger.

Just below the mouth of Tigre creek there is another exposure of the buff sandstone and its interbedded clays and sands, with grayish, limestone concretions of all shapes and sizes. Some of these concretions seem to contain masses of decomposed iron-pyrites only, but the most of them are fossiliferous. In the buff sandstone we find only specimens of oysters, all

other forms being confined to the concretionary beds or lenticular masses. Some of these contain all their fossils (except oysters, which remain as shells) simply as rusty casts, while in others all the forms are fairly preserved.

Among these are: *Venericardia planicosta*, Lam.; *Turritella, nasuta*, Gabb; *Volutilithes petrosus*, Con.; *Crassatella rotexta*, Con. var.; *Cytherea bastropensis*, Har.; *Pseudoliva vetusta*, Con.; *Conus sauridens*, Con.; *Cornulina armigera*, Con. var.

A very short distance above the Zapata-Starr county-line there is a long exposure, on the Mexican side, of bluish-gray clays, capped by a bed of fossiliferous greensand. The next exposure, however, is again of the buff sandstone, with very large concretions, and showing a distinct synclinal structure. In appearance, it closely resembles the materials of the Fayette beds on the Colorado river, north of LaGrange. Then follows the bluff, of which Dr. Penrose gives the following section:

	Ft.
1. Indurated, light-brown sand, ...	3 to 6
2. Loose, light-brown sand, ...	10
3. Gray clay, ...	5
4. Oyster-bed. *Ostrea alabamiensis* var. *contracta*, ...	1
5. Gray clay, ...	1
6. Oyster-bed, ...	1
7. Detritus to water's edge, ...	4

In this section the oysters, some of which are a foot or more in length, occur not only in the oyster-beds, but scattered through the buff sands also. Two miles below, the beds are still more clayey in their nature, as is shown by the following section made at Las Guerras bluff, the point at which the river makes its sharp turn to the northeast, 5 miles or more west of Roma:

	Ft.
1. Greenish-yellow clays, indurated, thin-bedded, and carrying gypsum and sulphur, ...	20
2. Oyster-reef. *O. alabamiensis*, var. *contracta*, ...	1 to 2
3. Calcareous bed, ...	1 to 2
4. Buff clays, partly indurated. Oysters, ...	8 to 10
5. Bright-colored, sandy clays, with gypsum, sulphur and lignitic matter, ...	8
6. Very hard sandstone, bedded and banded in brown, yellow and red colors, ...	12

The gypsum in No. 1, of above section, was of yellow color, and occurred in seams 0.5 in. thick, and in crystalline masses of

considerable size. I suspect that this bed will be found to be the base of the Frio clays, since my notes state that its dip is only 4 degrees, while that of the calcareous and underlying beds is about 7 degrees. The lower beds are referred to the Fayette on the strength of the persistence in them of the large oyster, which has been used as one of the characteristic fossils of this sub-stage.

The buff sands continued toward Roma, and the oyster-reef, with the same large oyster, was seen in the river-bank at that town. One mile below, however, where the final exposure of the buff sands was observed, no oysters were found.

Frio Clays.—This division has been instituted to comprise a series of gypseous clays, with sands and sand-rock, overlying the sands, properly referable to the Fayette beds. In age it belongs to the Eocene series, and, as the fossils show, to the Lower Claiborne.

Atascosa-Frio Sections.—The base, as seen on the Atascosa creek just above the mouth of the Weedy or San Christoval, is a yellow clay, with gypsum crystals.

While these beds are obscured for the most part on Weedy creek, and for some distance on the Atascosa, also, by the overlying Reynosa and later deposits, a few good exposures were had. At the mouth of Weedy creek we found below the later deposits:

	Ft.
4. Greenish, gray clays, massive, with quantities of gypsum, and with calcareous concretions arranged in lines and giving it a stratified appearance. Clays rusted in places, ...	8
5. Blue clay and sandy clay, laminated or bedded, varying in amount of sand it carries, rusty in places, ...	3
6. Laminated, green, blue and brown, or red, clayey sand, . . .	5
7. Brown and green sandstone, interbedded with yellow clay. Sandstone concretionary and highly indurated in places, ...	8
8. Brown sand uncompacted, ...	2

At the mouth of Comanche creek, 15 ft. of interbedded brown sands and sandy clays were found, but from that point to 0.5 mile south of the falls of the Atascosa everything seen belonged to the Reynosa and overlying beds. At this point, however, the section seen at the mouth of the Weedy was repeated, but with reversed dip. It is on the Frio, below the junction of the Atascosa with that stream, that the red-green

clays, with gypsum, the brown sands and the chocolate clay, weathering white, are best developed, and for this reason the division has been given its name.

At the crossing of the Oakville-Tilden road on the Frio we have the following section:

	Ft.
1. Silt, ...	10
2. Stratified silt, wavy, ...	10
3. Gravel of dark color. Pebbles, from the size of a pea to 6 in. in diameter, usually dark-colored, consisting of flints, petrified wood, chalcedony, agate, sandstone and quartz, . .	3
4. Lenticular bed of white calcareous sand, ...	0 to 1
5. Brown, clayey sand. Lines of bedding or lamination give it a twisted appearance, ...	2
6. Greenish-gray, sandy clay, with concretions, ...	6
7. Mottled, red-green clay at base, ...	1

One-half mile below, the twisted sand-bed, No. 5 of above section, outcrops 6 ft. in thickness above water, and is capped by 10 ft. of chocolate clays, laminated and weathering in light colors. These become quite plastic, and further down the stream are bedded, rather than laminated, and contain concretions of crystalline limestone, with manganese dendrites, similar to the pebbles so common in the Reynosa, which are, in all probability, derived from this bed. These exposures continue to the junction of the Frio with the Nueces, where the banks are composed of these clays weathered white.

One mile north of Oakville, a well, 100 ft. in depth, has on its dump only the yellow sands, purplish and red-green clays, with gypsum, laminated brown sand and siliceous gravel of these and later beds.

On the road from Beeville to Oakville, just on the Nueces side of the divide, a newly-dug well, about 70 ft. in depth, showed, below the Reynosa limestone, the following beds, which belong to the Frio clays:

1. Sandstone, very friable, containing both lime and clay.
2. Mottled clay, sandy toward base.
3. Laminated, brown sand-rock.
4. Laminated, sea-green and pink clay, with some vegetable matter.
5. Brown sand.
6. White clay at bottom.

Exposures of the same beds are found at several places between this point and Oakville.

Tilden-San Diego Sections.—The Frio clays are first seen on the Tilden-San Diego road, 3 miles north of the Nueces river, where they form the capping of a hill and occur as sandy clays, weathering yellow, but green when wet, and contain crystals and bands of selenite.

At Shiner's ranch, where the Tilden and San Diego road crosses the Nueces river, several wells have been sunk, all of which, from 100 to 125 ft. deep, pass through the Frio clays only, consisting of green and blue clays, with crystals of selenite and iron-pyrites. Fossils, *Ostrea* and *Corbula*, of distinct Lower Claiborne types, were found in the clays. From the best information we could obtain, the same conditions exist for a considerable distance westward along the Nueces valley. It continued along our line of section for about 2 miles south of the Nueces river, where we found the brown sands which we suppose to be Oakville.

Rio Grande Sections.—As has been described, the first exposure of the Frio clays on the Rio Grande was seen at Las Guerras bluff, west of Roma.

Their next appearance was 4 or 5 miles southeast of Roma, where there is a bed of gray clay weathering white, which is very unctuous to the touch, and contains many leaf-impressions. Ferruginous concretions or segregations, from 6 to 12 in. in diameter, occur in the clays, and are, in all respects, similar to those seen at Chalk bluff, on the Colorado. "Frequently small, white, calcareous concretions, and, sometimes, large clay indurations, with veins of crystalline calcite, are found." At the lower end, the exposure is capped by a more sandy stratum, which is partly indurated.

Three miles below, these same clays occur at water's edge, and are overlain by same stratum of sand, which here forms a bluff 15 ft. in height, with

"Concretions, fragments of worn, silicified wood, and a few broken pieces of an oyster. These latter have the appearance of being derivative, and not indigenous to the bed, and they are much rounded and rolled, and were very probably derived, during the deposition of the enclosing clays, from the great oyster-beds of the strata about Roma."

"Two miles below this are seen similar beds, but with no clay, the soft and indurated layers alternating with each other. The dip is 2 degrees north, 20 degrees east. . . . . Nine miles above Rio Grande City (only about 4 miles in direct line) are seen similar sands, with silicified trunks and branches of trees."

This last exposure shows a small seam of calcareous concretions, some ferruginations, and encloses some pebbles.

These sands, as I now understand it, belong to the Neocene beds, and may rest here in a synclinal basin of the Frio clays in the same manner as the later deposits do along Weedy creek. The same sands, I think, occur at Mier, west of Roma.

Penrose describes the final appearance of the Frio clays at Rio Grande City as follows:

"The town of Rio Grande City (Ringgold Barracks) is situated on a bluff of hard, white clay, rising some 50 ft. above the river, and indurated into a substance of a chalky consistency, though, chemically, it is only very slightly calcareous. It probably represents the light-green clays of the Fayette beds, and has become indurated by exposure to heat in a dry climate. The effect of such agencies would, also, account for its white appearance, as the characteristic pale-green color of these clays is, doubtless, due to their hydration. The bed shows a highly conchoidal fracture, contains iron-pyrites and is much jointed. The joint-cracks are frequently filled by veins of smoky quartz, ⅛ in. to 1 in. thick, often showing a globular surface. The bluff extends along the river for half a mile below town and 200 yards above it. Beyond these limits, it disappears under the gray river-silt."

Neocene.

Dr. Loughridge, in "Cotton Production in Texas," *Tenth Census Report*, vol. v., p. 21, makes the following statement in regard to the Texas Neocene.

"Immediately south of the Eocene, there is a belt of sandstone extending across the State that has been referred to the Grand Gulf, of probably Miocene age. Its northern limit enters the State at the lower part of Sabine county, and outcrops on the Trinity river near Trinity station, in Trinity county, forming a bluff of about 100 ft. in thickness. In Washington county, near Chapel Hill and Burton, the sandstone appears near the surface exposed in the railroad cuts; in Fayette county, at Lagrange, it forms a bluff over 100 ft. high on the south side of the river; in DeWitt county it outcrops in the high hills on the north and in the bed of the river at Hellgate ferry, near Cuero. Still southwest, from all that can be ascertained from reports and other sources, the upper limit of this group forms a line of hills, via Oakville, Live Oak county, southwestward through Duval county to the Rio Grande at Rio Grande City.

"The width of the formation is not great, being covered with the Port Hudson clays on the south along the entire coast. On the east it probably includes the long-leaf pine region, while on the Rio Grande it does not, so far as known, approach nearer to the coast than Hidalgo, where the first line of sandstone hills comes to the river. The rock is usually very coarse in character, and rather a conglomerate, in which a coarse, quartz grit is combined with a white siliceous clay as a cementing material. Sometimes it is massive in structure and often thinly laminated and fine-grained.

"These sandstones contain no fossils so far as known, and identification of the group is dependent wholly upon the position and character of its rocks."

The line between the Eocene and Neocene as laid down by him is very nearly correct—much more so than many which have been drawn since. In this paper, however, we can take up only those deposits which are within our area.

Oakville Beds.—The clays of the Frio division are overlain by sands, grit and clays which in their lithological character are generally distinct from the Fayette sands (from which they were, doubtless, partly derived), but, nevertheless, have a strong resemblance to them in places. At times, also, they lap far over onto the Frio clays, and possibly onto the Fayette as well, and we may pass from the lower sand to the upper without recognizing the separating bed. These upper sands have, for these reasons, heretofore been included in the Fayette in the various reports of the Survey. In separating them I have given the upper beds a local name, Oakville beds, which must be regarded as provisional only, since it is possible, and, indeed, probable, that a closer study and larger collections of the vertebrate and other fossils which may occur in them will necessitate a still further division. So far, the only fossils found are from the upper portion of the beds, and there is, therefore, room for older forms than those of the Loup Fork which are now recognized.

The deposits are those of rapid currents of shallow water, grits and coarse sand, cross-bedded, with some beds of clay, but oftener with balls, nodules or lenses of clay imbedded in the grit. Some of the sand forms a sand-rock which is apparently firm and hard, but much of it is so feebly coherent as to fall apart on a slight blow of the hammer. Local beds of conglomerate occur.

On the Nueces, the beds, which are here highly saliferous, are well exposed from Oakville to Fort Merrill, at which place they give place to the Pliocene. Here begin the silicifications of these materials, which become more and more prominent features of the deposits further west.

Only a few fossils have so far been found in these beds, but such as are determinable—*Protohippus medius*, Cope; *P. perditus*, Leidy; *P. placidus*, Leidy; *Aphelops meridianus*, Leidy, etc.—are sufficient to determine its age as Loup Fork.

Lapara Beds.—The Lapara beds, as shown on Lapara creek and Hog Hollow, on the opposite side of the Nueces, consist of

sands and clays interbedded and somewhat cross-bedded. The sands are coarse and sharp, often forming grits, and including pebbles of clay and calcareous concretions. The clays are jointed and parti-colored—light-red, green, etc.,—and in some localities appear as a conglomerate of clay pebbles. Fragments of bone are common in them, but they are often so worn as to prevent recognition. The fossils were submitted to Prof. Cope, who pronounced the horizon to be Blanco, and states that nothing from either locality indicates a horizon as low as Loup Fork.

When in the field the lithological difference between the Oakville and Lapara, at many places, was so little that these two terranes were often treated as one, except that fossils from different strata were always kept separate. Consequently, since the determination of the fossils has rendered necessary a division of the beds, it had to be more or less arbitrary in those places where no fossils were found or unconformity observed. For this reason, I find it necessary to treat the two divisions together here, although I have given to each the beds belonging to it, as I now understand them. It may be, however, that some of the beds of the northern scarp of the Bordas, which are here described as Oakville, may really belong to the Lapara.

Nueces Sections.—We first find these beds exposed in the banks of Sulphur creek at Oakville:

Lapara?

1. Surface, gray to black sand.
2. Gravel, in limy, yellow clays—black chert, silicified wood, quartz, small limestone pebbles, and agate—very variable in thickness.

Oakville?

3. (Highly eroded previous to deposition of No. 2.) Interbedded and interlaminated, greenish-yellow, orange and gray clays and sands, with much gypsum. Some kaolin present.
4. Alternations No. 3 with No. 5.
5. Brown sands, coarse, slightly cross-bedded, showing local seams with so much iron as to be red to dark-brown in color. Laminated in places. Some layers are much more indurated than others, and form table-rocks by erosion of softer underlying materials.

In places this sandstone shows a stalactitic weathering, and contains lime, limy clay and pebbles in nests, as well as a few laminæ of calcareous matter. Under the lens this sand seems

to be simply an aggregation of clear quartz-grains, sharp to somewhat rounded, with a few black, brown, yellow and red grains scattered through it.

At the ferry, on the Nueces, the banks are entirely composed of the brown sandstone No. 5 of Oakville section, and are 25 ft. in height. Exposures of the same bed are practically continuous for a little more than a mile down the river, when we find the following section:

	Ft.
1. Gray soil, somewhat clayey, ...	2
2. Interbedded and interlaminated sand and clays, in bright colors. Clays more or less sandy and weather white, ...	8
3 Interbedded, brown and yellow argillaceous sand and micaceous sand, ...	7
4. Greenish-yellow sands. Seams of red, sandy clay, with calcareous concretions, in places taking the form of laminated sands, with fragments and boulders of sandstone. The greenish sand has nodules of green clay included in it, ...	7
5. Yellow, fissile sandstone, interbedded with red or mottled clay, and containing clay pebbles, ...	6

This latter bed is sometimes green or brown when it touches the water's edge.

From this point to Bartlett's ford, with the exception of an outcrop or two of brown sands, the banks consist of lake-deposits (Pleistocene).

Bartlett's Ford Sections.—This ford is at the south end of a stretch of the river running south-southeast, or nearly on the dip of the beds. The river runs straight for nearly half a mile, and the lower part of the bank for a great part of the distance consists of the brown sand-rock (No. 7 of section), with concretions, some of which are calcareous, some septarial, and from 3 to 4 ft. in diameter, but generally friable, especially if near the water-edge, their cementing-matter being seemingly clay. The limy concretions, however, become indurated and give the bank a very rough, knotted appearance.

Above the ford we have the following section:

1. Black, sandy soil, sometimes more or less clayey.
2. Brown sand—river silt.

Unconformably on

Lapara?

3. Yellow sand, apparently stratified, cross-bedded, calcareous concretions in lines of stratification.
4. Bed of gravel; black flint, agate, jasper, quartz, limestone, quartzite, silicified wood; from ⅛ to 10 in. in diameter, angular to rounded in form, in a matrix of coarse, sharp sand of dark-brown color.

	Ft.
Unconformably on	
Oakville?	
5. Interbedded and interlaminated sands and clays, with gypsum.	
6. Mottled-brown and gray, rusty clays and sandy clays, ...	5
7. Brown sand-rock, ...	15

Further down the river some changes were noticed in these beds. The dip carries the interbedded and interlaminated sands and clays of the Oakville and the overlying gravel-bed below the water-level, and the cross-bedded sand, with its capping of silt and sand, forms the entire bluff. In places a line of calcareous pebbles is found at the contact of Nos. 2 and 3, containing numbers of fragments of shells of *Unios*.

The sands of No. 3 are not pure sand, but contain lime and clay in varying proportions, some of it being sufficiently plastic to ball readily when wet. At times, the lime is in the form of concretions, and, at others, a line of these concretions, together with many fragments of *Unios* mixed through the clayey sand, form the upper surface, upon which was deposited the later brownish silt and sand. Numerous fragments of *Unios* were found in the brown silt, as well as at its base.

The next section was 1 mile south of the last, and again shows these lake deposits resting on the Oakville beds:

	Ft.
1. Soil, gray sand, ...	0 to 1
2. Gray sand, with gravel, passing downward into a bed of gravel, pebbles mostly siliceous, in brown sand-matrix, with a little lime toward top of bed. Gravel up to 8 in. in diameter, but no tendency toward any arrangement according to size, although bedding-lines are shown. Only a few black pebbles, some flints, fossil-wood, agate, chalcedony, quartz, etc., . .	6
Traced up the river for a short distance, we found that this gravel-bed forms a heavy conglomerate, with a ferruginous and brown sand-matrix, increases to 12 ft. in thickness, and contains a bed of *Unios*.	
A mastodon tusk was found imbedded in this gravel.	
Unconformably on	
3. Sands, with seams of limy clay and lime, color gray, with rusty and purple streaks, pebbles of clay, few siliceous pebbles, sand coarse to fine in grain, passing into grit, with pockets of conglomerate. Cross-bedded in places, laminated in others. A short distance up the river this bed becomes coarse and more gravelly, and gradually thins out under the bed of ferruginous conglomerate, which is the continuation of No. 2, ...	6
4. Laminated, mottled-green clays, weathering yellow.	
5. Light, sea-green sands, with harder concretionary spots and bands, passing downward into brown sandstone, with knotty weathering. These are the sands of Bartlett's ford region, .	10
6. Blue-green sand, with calcite inclusions.	

Up the river a few hundred yards, at the mouth of a creek, we found another exposure of the same character.

		Ft.
1.	Soil, gray sand and gravel,	2
2.	Gravel-bed, similar to south end of No. 2 of last section,	6
3.	Mottled-green, red clay, yellow and calcareous at base,	6
	Unconformably on	
4.	Sand-rock, same as No. 3 at south end of last section. Laminated to bedded in structure, little or no gravel in this section, except at base. Narrow fissile bands of lime-concretions occur, showing a rapid change to limy sands in places,	14
5.	Green clay, No. 4 of last section,	20
6.	Interbedded, green and brown sandy clays,	3
7.	Light, sea-green sand,	4

One-half mile below, No. 4 of above section again forms the bank of the river, and 1 mile below, contorted sands, like those at Bartlett's ford, occur. Similar exposures are seen for 4 miles below Bartlett's, Nos. 4 and 5 of above section being the principal beds seen. The only difference is that the sand-rock is fissile, interbedded with red clays and coarser-grained sands, with much mica. Below this, the clay occurs in the sand in nodules and as pockets of clay-gravel. The clay is the same as that underlying the sand. There is, apparently, an unconformity between Nos. 4 and 5.

Below this, the river makes a great bend, and an old channel crossing the neck shows red or pink sandy clay (No. 3 of section) overlain by gravel and contorted sands. Similar exposures are seen at Gussettville ford. Here the red or pink clay appears at base of section, unconformably below the brown sand-rock. The surface of the clay is very irregular, and boulders of the clay occur in the overlying sand.

Gussettville Section.—In a basin eroded in the Oakville beds at Gussettville ford, we find a deposit of cross-bedded or contorted sandy clay similar to that at Bartlett's ford.

Taking it as a whole, we have here, at each end of the exposure, a bed of sand-rock which, in appearance, simulates the finest dimension-stone, and which is really so slightly compacted as scarcely to be classed as a rock at all, but is simply a pack-sand. The layers are from 8 in. to 3 ft. in thickness, and separated by bands of clay conglomerate. The sands are sharp and occasionally quite coarse, and contain pockets of clay and calcareous concretions. The clays, which are quite pure in

places, are of light-green, lavender and purple tints, and are rarely stratified, but lie as a conglomerate of less or greater masses commingled in every way. Some of the clay-pockets in the sand-rock weather out, leaving cavities similar to those noted between Brenham and Chappell hill in similar beds.

The upper surface of these sands is highly eroded, being from 10 to 12 ft. above water-level in places at either end of the section, and, in the center, below the level of the river. In the basin thus formed is a deposit of cross-bedded sandy clays, with calcareous concretions, like that of No. 3 at Bartlett's ford.

Immediately overlying both the sands and cross-bedded sandy clay is a conglomerate containing large quantities of silicified wood, black flint, agates, limestone, jasper, sandstone (from underlying beds), etc., the general appearance tending toward black.

In some places it appears as pockets or beds of gravel, with small admixture of sand; at others, as the greenish-yellow sandy silt, with more or less gravel mixed through it without any regularity, except that, in rare instances, lenses of gravel were observed.

This deposit is overlain by a brown to black deposit of later material, which also contains gravel and fragments of *Unios.* The thickness of each of the deposits here mentioned is extremely variable.

One mile below, the first of a range of hills touches the west bank of the Nueces. From the top of the hill, 120 ft. above the river, we look out over a comparatively level, mesquite-covered country to the north and east, while to the south and west it suddenly becomes very hilly. The hill is covered with detritus, and is very brushy, so that a satisfactory section was not obtained. The top was of Reynosa materials for 20 ft., underlain by interbedded sands, sandstones, grits and clays. The upper beds of sandstone (Lapara) are coated with lime or limy clays, and, under the lens, appear to be composed of rounded grains of clear quartz, with scattering grains, red and black. No mica seen.

Thirty feet below the top the sandstones show a rounded, bouldery surface. While of the same general character as those above, they contain mica, are more highly indurated,

consist of browner and coarser sand, and are interbedded with clayey sands, rather than clays like those above. One ravine gave a few disconnected exposures of very coarse grit in flags and laminæ, with false-bedded clayey sands. Sandstones and sands appear also at lower levels, and then a bed of red clays, from 10 to 20 ft. thick. The bank, 15 ft. in height, is a bed of brown sand-rock, thinly stratified with knobby, indurated patches, similar to No. 4 of last section. From a bed of grit, about half way up the hill, bones and a tooth of a small horse were taken. From here to Fort Merrill, 4 miles, the same sands, with interbedded clays, were seen.

Fort Merrill Section.—Fort Merrill was situated on the west side of the Nueces, and at an elevation of 120 ft., barometrically, above the river. Southwest, the ground slopes gradually upward some 50 ft. more, and the top of the elevation is capped by Reynosa. This material is here quite friable, and weathers to the complete semblance of a hillside capped with Austin limestone. It is slightly jointed, and the principal joints have a compass-bearing of N. 8° E., with cross-joints at irregular angles and running irregularly.

A section was made from the bank of the Nueces to top of hill, following up the gulch known as Fort Hollow, but like all such sections this one lacks absolute continuity, and the relationships of some of the individual members were, therefore, somewhat obscure. The general succession was:

	Ft.
1. Reynosa capping,	20
2. Interbedded sands and clays of brown, yellow and orange colors, with bone fragments,	130
3. Stratified and laminated sands and clayey sands,	20

No. 3 shows on the bank of the river and for some distance up the gulch. The heavier beds of sand are dark-brown, and on the river show little or no cross-bedding. Some of the strata are composed of fine sand, hard and firm with clay inclusions. Under the lens the larger mass consists of clear quartz-grains, but many red and black grains occur in it. The interbedded materials contain only small amounts of clay. These same beds show on Fort Hollow two benches of somewhat solid, light-brown, cross-bedded sandstone, separated by laminated and cross-bedded sandstone, with beds of pebbles and calcareous concretions.

Immediately above this came a bed of mottled-reddish, orange, green and purple clay, very variable in thickness on account of erosion, followed by interstratified clays and sands. These sands and clays are false-bedded. The clays are plastic when wet. The sands are often coarse and gritty, with clay pebbles and calcareous concretions and many bone-fragments. The mottled clay is a very persistent member of this section, but has, as I have said, a very variable thickness. Sometimes it is a mere line, an inch or two in thickness at the base, while at other localities it forms almost the entire face of the bluff. In the former case the gravel is present in much larger quantity than in the latter. Where these clays are overlain by the sandstones the latter show a great deal of false-bedding. For the most part these beds only appear in detached outcrops along the hollow, the materials more often occurring as fragments of a great conglomeritic mass overlying them. The mass contains fragments of these sandstones weighing hundreds of pounds, together with large amounts of clay, calcareous pebbles and siliceous pebbles. Some few teeth and fragments of bone were found in them.

Lapara Sections.—Lapara creek is a tributary of the Nueces, having its junction with that river on its eastern side, about 17 miles south of Oakville, nearly opposite Fort Merrill.

Near Mr. Pugh's we found several excellent exposures of these beds in the bluffs which form its banks:

	Ft.
1. Light-brown or yellowish silty material, with bands of lime underlain by gravel. This passes upward into black soil, with less quantity of gravel toward the top.	
2. Gravel-bed, consisting of silicified wood, jasper, black-flint, sandstone, quartz, agate. Matrix, brown sand at base, passing upward into No. 1. Pebbles irregularly distributed, small and large together, cross-bedded in places, and at others containing considerable calcareous matter,	
Unconformably on	
3. Yellow and yellowish-green silt, with lime concretions, . .	8 to 10
4. Sandstone, friable, coarse-grained at base.	

One-fourth mile nearer the river we again find these same beds, but in slightly different development:

1. Black, sandy soil.
2. Yellowish-brown to orange-colored sandy clay, carrying a small amount of gravel and fragments of *Unio*,

Unconformably on

3. Gravel, in brown sand-matrix, irregular, in places scarcely showing pebbles at all, at other, heavy irregular beds, and passing into the yellow-brown silt, with lines of calcareous concretions,

Unconformably on

4. Interbedded sands and clays, somewhat cross-bedded, indurated, often gritty. Sand coarse and sharp, clays jointed and parti-colored.

Fragments of bone were common from bottom to top of the section, but those above the gravel were of mastodon (?) and other large vertebrates, while in the sand and clay of No. 4, I found alligator, horse, gar, turtle, etc. The sands are somewhat indurated in places, and are often of the nature of grit; it was in this material that the better specimens of gar, etc., were obtained.*

On the Nueces, 200 yards north of Barlow's ferry, there is an exposure of red and light-green clays, interbedded with laminated sands. The clays are somewhat sandy, but still quite plastic. The sands are thinly-laminated, and contain occasional laminæ of ferruginous material. In places, these sands are sufficiently hard to form table-rocks and extensive benches along the river. The beds are from 8 in. to 2 ft. thick, while the clay-seams are not more than 1 ft.

Overlying this series is a sand, capped unconformably with later gravel, containing many calcareous concretions, brown quartzite and chert pebbles. Over this occurs the yellow silt, with abundant lime concretions.

The cut for the wagon-road at the ferry gives evidence of three distinct periods of fluviatile or lacustrine deposits, showing that number of old soils, with beds of *Unios* and pockets of gravel between the different beds.

We also found the Lapara beds well-developed in a gulch 1.5 miles north of the ferry. Here the same interbedded sands, or grits and clays, occur, capped with gravel as before. These sands are very much cross-bedded, and in places are so coarse as to form a grit, with pebbles of clay and calcareous concretions. The clays were laminated, and in places showed simply as a conglomerate of clay pebbles.

There was seemingly a small disturbance in the strata at this

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* See Prof. E. D. Cope, "On the Genus Tomiopsis," *Proc. Am. Phil. Soc.*, vol. xxxi., pp. 317, 318, 1893.

place, resulting in an anticlinal, the axis of which had a direction of N. 63° E. (compass), and dips of 6 deg., N. 27° W., and about the same to the southeast.

At the north end of section there was a bed of sand, with large numbers of calcareous concretions, the lower part of which closely resembled the Reynosa. It was unconformable on the clays and sands.

Bones were found in the gravel, seemingly of large mammals, but bones and teeth of smaller animals were very abundant throughout the interbedded sands, and it was from these that Prof. Cope determined the Pliocene (Blanco) age of the beds.

Two and one-half miles below Barlow's ferry we found the Lapara sands outcropping and strongly altered, overlain by Reynosa, and this by brown sand. The Lapara sands here consist of stratified, highly indurated brown sands containing many pebbles in places. It has a botryoidal weathering, and contains quartzite bosses arising from metamorphism (Las Tiendas phase).

A short distance below we found the following section:

	Ft.
1. Brown sandstone, laminated,	5
2. Conglomerate of calcareous pebbles, with probably one-third siliceous pebbles in a calcareous matrix,	5
3. Brown sandstone, laminated,	1
4. Conglomerate of pebbles, coarser at top, finer below, in matrix of brown sand,	5
5. Covered to river,	10

The next exposure of this material, in a gulch making into the river, shows the change of the brown sand and gravel, No. 3 and No. 4, to a more perfectly stratified, limy material, which is overlain as in the previous section by the beds Nos. 1 and 2. In some localities No. 2 seems cross-bedded, and the lines of pebbles are diagonal to plane of stratification. No unconformity was observed between No. 1 and No. 2, and Nos. 3 and 4.

A short distance west of this locality were several exposures of quartzitic materials identical with the "flint" of the Tiendas and the Picacho area. The points at which these knobs or bosses occur are topographically higher than the level of the Reynosa beds in their immediate vicinity.

Tilden-San Diego Section.—Two miles south of the Nueces, on the road between Oakville and Gueydan's ranch, we found, overlying the Frio clays, a soft brown sandstone, with limy weathering, which we have tentatively called Oakville. The exposures were too poor for us to determine this positively, and my impression was that it did not represent the base of the beds as seen at Oakville, but was some higher bed of the division, even if it did not belong to the Lapara. There is also a possibility that these beds lying between this point and Gueydan's may be Reynosa, like that on Weedy creek, but their appearance is more nearly like that of the lower beds. Three and one-half miles southeast of the river a well-section gave:

	Ft.
1. White, limy clay,	2
2. Gray and brown sandstone,	0.5
3. Clay, limy and weathering white,	10

Where freshly broken, this clay has a reddish tinge, like the Reynosa.

As we gradually ascended from the river toward Gueydan's, we passed other small exposures of similar sands and beds of brown gravel, until at a small creek, 4 miles north of the ranch, we had its final exposure. Following this came outcroppings of indurated white, limy clays, with jointed weathering for a mile or more, and then a gravel-covered area of like distance. A mile before we reached the ranch, we came into a series of clay-deposits, which showed at the base light-greenish clays overlain by very clayey limestone or limy clay, and this by pinkish clays, such as occur in the Lapara section.

At Gueydan's, which is in the valley at the foot of the Bordas and 380 ft. above sea-level, a well gave us the following section:

	Ft.
1. Soil and subsoil,	3
2. White, limy clay, with calcareous concretions,	10
3. Quicksand,	5
4. Laminated, pinkish clay, indurated and containing pebbles of chalcedony, siliceous materials and silicified wood,	9

A thin seam of lignite was found in top of clays.

From Gueydan's the ascent of the Bordas is gradual, it being one of the few points where there is no very pronounced scarp. The distance to the divide is 13 miles, and the difference in

elevation only 270 ft. The exposures along this gentle incline were not very satisfactory, and the section was made by visiting some of the detached hills, which are the monuments of the more northward extension of these deposits.

Among these hills, in Duval and McMullen counties, we may mention Loma Alta, Las Chusas, Rossillas, etc.

At Las Chusas, on the northern slope of the Bordas, which by barometer is 130 ft. from base to top, we found the greater portion of the hill so covered with detritus that little could be made of it.

The following beds were observed, beginning with the top:

	Ft.
1. Coarse, brown sandstone,	2
2. Interbedded sands and limy clays,	2
3. Interbedded brown sandstone and white, limy clay,	3
4. Interbedded sand and limy clay,	4
5. Massive sandstone,	5

Other localities on hillside show these beds as laminated sands, coarse-grained, with many black specks, brownish-gray in color, with clay inclusions and many round-ended worm-borings filled with sand.

6. Gravel-bed, conglomerate in places. Pebbles of flint, brown clay and crystalline dendritic limestone in a matrix of sand.

Below this there appeared to be a brown sand, coated with limy clay, passing downward into bedded and laminated sands.

(A deep gulch on left of road, passing from the top of the Bordas down into the valley, exposed similar bedded and laminated sands.

The Rosillas hills, which mark the scarp of the Bordas west of our line of section, gave a still more extended exposure.)

The upper beds are the same as those described at the Chusas, below which are found:

7. Conglomerate sands and clay, ... 3 to 5.

This bed is very variable, being in one part of the hill simply a brown, laminated sand and, again, a very characteristic conglomerate. This conglomerate consists of brown to olive-colored clays, in balls from 3 to 10 in. in diameter; each ball stuck full of dark, siliceous pebbles, making a regular plum-pudding. The matrix is a similar clay, and this is interbedded with coarse, brown sand or grit, which is also conglomeritic in places. These clay-balls carry pebbles on their surfaces as though, while in a plastic state, they had been rolled over a gravel-bed. Among all the balls broken, not one was found with a pebble entirely imbedded in the clay. The pebbles are small, and are all of siliceous material, black flint, porphyry, white quartz, jasper, etc.

In places the clay is granular, and even in pebbles, and lies in flaggy layers of grit as it is mixed with the brown sands. It is as variable as possible, from coarse pudding-stone to laminated grit-beds.

		Ft.
8.	Limy clays, weathering white or greenish-white. Dried so far in that their real color could not be seen, but it is probably olive-green, ...	10
9.	Brown sand-rock, with limy coatings in places.	
10.	Yellow, calcareous clay, with lime in vertical seams, . .	10
11.	Same as No. 9.	
12.	Red to gray calcareous clay, with calcareous concretions weathering white, but, when broken, has a pinkish tinge. This is similar in character to that in well-section at Gueydan ranch.	

Las Tiendas.—About 7 miles south of Gueydan's ranch, just before reaching the highest point of the Coastal slope on our Tilden-San Diego section, we found two or three rock-masses, from 15 to 20 ft. in diameter, resting on laminated brown sandstone, and this on gypseous clays. These masses are of quartzitic material, somewhat like the Picacho rocks, and, doubtless, have a similar origin. They are of gray color and, in many places, show highly-polished surfaces from the action of blown sand (desert-weathering). The harder portions closely resemble flint in appearance, have a conchoidal fracture, and are known as flint-rocks to the people living in the vicinity. An examination of one of the rock-masses showed bedding at base, succeeded by a contorted or wavy structure, resembling interbedded and interlaminated sands. Another showed two heavy bands of quartzite, separated by a stratum of laminated sand 1 ft. in thickness. They also exhibited evidences of clay-inclusions. The entire character of the masses seemed to place them as local indurations of the sands and clays of the Lapara. In the drift on hillside we found pebbles of chalcedony, silicified and opalized wood and various siliceous pebbles.

Loma Alta.—Twelve miles southwest of Gueydan's, is a hill of somewhat similar materials, but lower in the series. Here there are 40 ft. of sandstone, grit and conglomerate, underlain by 50 ft. of clayey sands.

The upper beds of sandstone are made up of sharp sands, grit, black and purple fragments of water-worn silicified wood and fragments of light-green and yellowish-white and blue clays. The underlying uncompacted light-brown or yellow sands contain many thin seams of calcareous matter. The upper sandstone resembles that found on the Rio Grande below Roma and at Mier.

At Brown's ranch, south of Loma Alta, a well-section shows

10 ft. of brown sandstone underlain by blue grit and sandy clay. Between here and the Picachos a band of striped brown sandstone crossed the road, dipping southeast at an angle of 5 degrees. This sandstone was gritty in places and carried clay-inclusions. From its general character, I believe it to be a part of the Oakville beds.

Picacho Hills.—This name is given to a cluster of hills, four or five in number, in Duval county, 6 miles southeast of Loma Alta and lying in the Nueces valley, between the "Bordas" and the McMullen county-line. They rise in a comparatively level plain and are so surrounded by beds of sand that no connection can be gotten with the beds of any other locality.

As far as my observations extend, this area is entirely unique in the Texas Tertiary. It comprises materials which belong to the Oakville sands, but in their present condition they differ widely from the body of that formation.

The trend of the hills, which are nowhere over 100 ft. higher than the valley in which they stand, is northeast-southwest. A section was made at their southwest point, which showed the different beds dipping at an angle of from 75 to 80 degrees to the southeast.

Beginning on the north side of the hill, the first 40 ft. of its side was so detritus-covered that nothing could be made of it. Then followed these beds:

		Ft.
1.	White calcareous clay stone, spotted with yellow,	2
2.	Porcelaneous siliceous rocks, opal in part, with bands and net-work of chalcedony,	12
3.	Ferruginous seam (this has been prospected for gold),	4
4.	Same as No. 2,	15
5.	Interbedded claystone and porcelaneous rock, with thin seams of ferruginous material like No. 3,	65
6.	Same as No. 2,	8
7.	Porcelaneous rock, with seams of calcite (dog-tooth spar principally),	15
8.	Aragonite, brown and white, banded, knotted and twisted in places,	20
9.	Detritus-covered,	40
10.	Knob of porcelaneous rock, with chalcedony seams,	30

A short distance north of the main section another was made, beginning at the Aragonite bed, No. 8 of above section.

8. Aragonite.
9. Claystone, banded yellow, brown and white.

10. Kaolinite.

11. Claystone, similar to No. 1, but somewhat ferruginous and dipping 75 degrees southeast.

12. Calcareous sandy claystone, dipping southeast at a low angle (from 5 to 6 degrees).

The two analyses given below were made by Dr. W. H. Melville of two samples of material from No. 2 of first section, and show their opaline character:

	Per Cent.	Per Cent.
Silica,	88.16	86.38
Ferric oxide,	0.58	3.00
Alumina,	1.23	2.91
Water,	8.84	6.19
Lime,	0.73	0.99
Magnesia,	0.29	0.21
	99.83	99.68

These porcelaneous rocks were also examined by Dr. Osann, who regarded them as the result of infiltration of hydrous silica in hot solution and consequent alteration of the Tertiary marls. A number of the specimens collected show that the marl was cracked in every direction and that these fissures are now filled with chalcedony, while the marl is changed to a porcelaneous substance.

The lithological character of the unaltered materials is very similar to portions of the Oakville sands. Similar association of aragonite, chalcedony, kaolin, etc., have already been noted at Peeler's ranch and in the King hills in the Fayette sands,* and we found strings of chalcedony in the clays on the river bank at Rio Grande City; only in these other localities the beds all have their normal, almost horizontal, position, while at the Picacho hills they are almost perpendicular. The causes which operated on these materials has also changed some of the later materials in somewhat similar manner, but less extensively.

Los Angeles Sections.—Certain beds on the edge of the "Bordas," along the Mexican National railroad, are also seemingly members of this division. Just east of Ochoa, and about

* The Picacho Hills were originally referred by me to the Fayette sands, and it is possible that they may belong to those beds, but their connection with the Oakville-Lapara deposits, and the occurrence as stated of similar rocks throughout the Neocene, seems to demand its reference as here given.

36 miles from Laredo, a low line of hills, being part of the escarpment, gave the following members:

Beginning at the base of these hills we find a brown sandstone which contains yellow-brown clay-ball inclusions. It becomes conglomeritic higher up the hill, some of the beds being flaggy, others heavy-bedded, with pebbles as much as 5 in. in diameter. A single stratum will show a number of feet of sandstone entirely free from pebbles and then pass into a regular pudding-stone. Some of the sands are banded in colors, but the greater part are massive, brown, gray or black sand, with pebbles of clay.

Imbedded in these sands, and lying as boulders on the top of them, are masses of rock like those described at Las Tiendas and around the Picacho hills, which are proven by their connection here to be simply indurated aggregations of these Neocene brown sands.

The vast amount of drift found here is the result of the disintegration of these sandstones and conglomerates, and is predominantly black or dark-colored, containing basalts, porphyries, flints, some quartz and other siliceous pebbles.

The quartzitic or flinty boulders are of all sizes, some of them having a base of 20 sq. yards or more and being from 10 to 12 ft. high, while others are only a foot or two in diameter. They contain pebbles in places and show desert-weathering, as elsewhere.

One mile east of this line of hills there are two masses of still greater size, covering from 30 to 40 sq. yards and fully 20 ft. in height. Their bases are enveloped in yellow or brown sand. Just at the foot of one of them an excavation has been made which shows:

	Ft.
1. Brown silt,	8
2. Yellow, calcareous sand, with gravel,	12
3. Light-brown, shaly sandstone, micaceous,	20

A hundred yards to the right the Reynosa caps the "Bordas," which is probably from 30 to 40 ft. higher than the tops of these masses.

At Gray's ranch (La Gloria), Duval county, we found a small exposure in San Diego creek, which may be referable to this division, although it probably is Reynosa.

		Ft.
1.	Yellowish, brown sand, indistinctly bedded, ...	10
2.	Brown sand and sand-rock, with seams and strings of clay. In places the clay becomes thicker, and is interstratified with the sand, or forms a string of pockets. Clay very plastic, white to green in color, ...	10

In the brown sand we found masses of the flinty or opaline rock, such as is described under "Las Tiendas."

Rio Grande Sections.—On the Rio Grande the only exposures of the Neocene beds observed, in addition to that described in connection with the Frio clays, were:

Two or three miles below the Starr-Hidalgo county-line, and about a mile from the river, "is a bluff of semi-hardened sharp sand, with lenticular seams of coarse sand and siliceous pebbles from $\frac{1}{16}$ to $\frac{1}{2}$ in. in diameter, also white calcareous nodules, 1 to 3 in., and seams of calcareous gray clay." The bluff is 50 ft. high, the lower portion being composed of these sands, which are overlain unconformably by from 10 to 12 ft. of Reynosa conglomerate.

Two other small exposures were found just at water's edge. One of these was 10 miles north of Edinburgh, and the other across the river from that town and underlying the Reynosa limestone.

The first exposure is probably Oakville, but the two latter are more probably Lapara.

Lagarto Beds.—On Lagarto and Penitas creeks occur a series of beds of clay and sand, occupying a higher place in the Neocene than do the deposits described as Lapara sands; and while they may be simply the upper portion of the Lapara, or the lower part of the Reynosa, they are provisionally separated for the purpose of description. They are almost everywhere exposed in direct connection with Reynosa limestones and clays.

These sands and clays occur overlying the Lapara sands in the coastal slope and, apparently, with considerable unconformity across Nueces, Duval and Encinal counties, as is shown by the exposures and the well-sections which we obtained.

In the breaks of Lagarto creek at Lagarto, the top of the section is a calcareous sand-rock passing in places into the Reynosa phase of sandy lime-rock. The various exposures give the following section:

1. Brown, calcareous sand-rock.
2. Adobe.
3. Adobe conglomerate.
4. Clay, with pebbles.
5. Brown sandstone.
6. Calcareous conglomerate in calcareous clay, passing downward into mottled greenish-gray and reddish-brown clays, in which strings of limestone from the overlying calcareous beds run down from 6 to 8 ft. Much of this material contains quantities of semi-crystalline limestone, with manganese dendrites. In fact, the manganese occurs in the clays as well, and appears to be characteristic of the beds both here and elsewhere.

Further down the gulch this bed of clay No. 6 gradually becomes more limy, and finally passes into a mottled sea-green and red clay, similar to No. 6 of Ramireno section. The base near the creek was covered with creek-gravel and silt, with numbers of recent land-shells. This section is 55 ft. from top of hill to base, of which the upper limestone shows 20 ft. in one locality. Great variability is a characteristic of the deposits. In one place there is a bluff of the clay No. 6 of this section, which gives a clear exposure of it 25 ft. in thickness. The colors are all light—lilac, lavender, sea-green, greenish-brown, and mottlings of these colors. The clay is jointed, and many slips or slickensides are seen. The top shows the same limy phase noted at first locality, and is overlain by the sandstone No. 5, conformably. Upon a cursory examination this would seem to be the case only in certain localities. Within 50 yards of the exposure just described is another in which the sandstone rests directly upon the clayey portion of the bed, only a slight pocket of calcareous conglomeritic material appearing in its proper place between them. This sandstone can, however, be traced directly around the crest of the hill, and is found to have the limy material first appear in it as wedges; a little further on the lime is interstratified with it, and finally it becomes a calcareous bed. These seeming unconformities are, therefore, due only to the variable amounts of lime, sand and clay entering into the composition of the bed at any given locality.

Siliceous gravel occurs throughout this bed in abundance, both in the sandy and in the limy portions. These pebbles are frequently of good size, but often only $\frac{1}{8}$ in. or less in diameter, giving the deposit the character of a grit.

The sands and clays described above are found, also, near the mouth of Lagarto creek, at Chandler's bluff, where the following section was made:

		Ft
1.	Limy sand or sandy limestone, weathering in caves, cross-bedded in places, and containing siliceous pebbles, . .	10
2.	Clay and sand, yellow to white in color, in a very irregular bed, being a string of pockets in places and, at others, widening out into stratified or coarsely-laminated yellow, white and brown sands and clays, ...	0 to 8
3.	Sand, brown to light-gray, laminated, containing mica, siliceous and calcareous pebbles, and passing into a bed of gravel in a brown sand-matrix, ...	10
4.	Reddish clay? (detritus-covered in part), ...	10
5.	Mottled clays passing upward into limy clays, as in No. 6 at Lagarto. These clays, instead of weathering into perpendicular bluffs, as at Lagarto, are in steps, as though composed of harder and softer materials bedded. Beds from 6 to 8 in. thick,	15
6.	Light-brown compact clay, weathering gray. To water's edge, .	5

On Penitas creek, good sections were found at several localities.

The base of one of these sections is the highly-mottled, limy, sea-green or greenish-gray and red or pink clays (No. 6 of previous sections), the red clay of which is highly charged with manganese.

On the irregular upper surface of these clays (which here lack the upper capping seen elsewhere, although large amounts of lime occur through it) are laid down the ash-colored or yellow clays of the *Equus* beds. At the base of the *Equus* beds there sometimes occurs a deposit of gravel, from a few inches to a foot in thickness, but this is often lacking. Irregular stratification-lines appear on weathered surfaces and above the gravel, which is principally composed of pebbles of limestone, and these occur not only in beds at base, but also throughout the limy clays. The clays also contain lignitic pebbles. Some teeth were found in these beds.

Another section lower down the creek shows:

		Ft.
1.	Stratified sand, limy.	
2.	Cross-bedded, limy sand, interbedded with clayey sand, . .	8 to 10
3.	Conglomerate masses of brown sandstone, 2 ft. in diameter, calcareous and siliceous pebbles, ...	0 to 6
4.	Massive sand-rock, with lime. Weathering in perpendicular bluffs, with cavities, and containing clay-inclusions at base, .	6
5.	Mottled, sandy clay, ...	4
6.	False-laminated sand, ...	3

Variability is the most constant characteristic of these beds. Nos. 3, 4, and 5 of above section are represented a hundred yards away by a single bed of sand. The creek gave numerous similar exposures, the mottled clays being the principal bed, the interbedded sands and sandy clays and lime being less in amount.

Reynosa Beds.—This designation was first given by Dr. Penrose to a bed of limestone found at the Mexican town of that name, opposite Edinburgh, Texas (first described as Cretaceous, by Mr. Schott, in the *Report of United States and Mexican Boundary Survey*), and afterward extended by myself to include certain conglomerates in lime-matrix occurring on the Rio Grande and elsewhere.

The limestone of the Reynosa was not only observed by Mr. Schott, at Reynosa, as described in the *Report of the Mexican Boundary Survey*, but previously between Victoria and San Antonio, by Dr. G. G. Shumard,* in 1855. He says, under the heading of "Upper Cretaceous:"

"Commencing in the southeast, these rocks occur at a number of points along the route traveled by your expedition between Victoria and San Antonio. They do not, however, present here a vertical thickness of more than 20 or 30 ft. and are confined to limited areas."

In his *Journal of Geological Observations* (p. 56 *et seq.*), he describes the occurrence of these beds along the route traveled, saying of them, "which I have no hesitation in referring to the Cretaceous group."

Following Dr. Shumard's determination, Mr. A. R. Roessler, in compiling a series of maps which were published in 1876 by the Texas Land and Immigration Company, colored the portions of those in this area covered by these deposits to represent Cretaceous.

It might seem strange to some that deposits so widely separated as Pliocene and Cretaceous should be called the same by such observers as Shumard and Schott, but there are many places where the Reynosa deposits so closely resemble those of the Austin limestone that, were they found in a Cretaceous area,

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* A partial report on the "*Geology of Western Texas,*" p. 10, Austin, 1886.

they would be classed as belonging there even by those better acquainted with the Cretaceous than were these two observers.

In the description of Goliad county by Mr. Loughridge, in "Cotton Production of Texas,"* we find the following reference to the Reynosa.

"The banks of the San Antonio river are high, and in them, as well as in those of smaller streams, there outcrops a whitish clay or adobe (Port Hudson), which was used as the building-material in the old Mexican houses and missions."

The very variable series of beds intended to be included under this name has usually at the base a conglomerate of pebbles of materials derived from different sources imbedded in a lime-matrix, often indurated, sometimes tufaceous, sandy or even clayey, but in many localities it is wanting altogether. Above this is, occasionally, but not always, a series of interbedded clays, limy clays, limy sands and sandstone, with some pebbles in places, which may be identical with the Lagarto beds, and the whole is capped by the Reynosa limestone proper, which is usually a tufaceous lime-rock, but often so mixed with clay or sand as to lose that character. There are very few exposures which show the entire series of beds. In places along the middle Rio Grande, the basal-bed of conglomerate is all that is seen, while in the divides the basal and uppermost beds are both found, but without any of the intermediate deposits. This is the more common mode of occurrence, and no other beds in this area have anything like such wide distribution.

Mr. McGee's Lafayette formation probably includes the beds here described. However, I continue the name given by Penrose and myself until such time as more detailed examinations across our coastal area have determined, as I believe they will, the stratigraphical connection or the faunal equivalency of these beds with the recognized Lafayette.

Atascosa Sections.—The hills east of Castroville are composed of Cretaceous materials belonging to the *Exogyra Ponderosa* marl division, and are capped with Reynosa limestone underlain

* *Tenth Census Reports*, vol. v., p. 110.

by nearly 50 ft. of gravel in a yellow clayey matrix. The tufaceous limestone in places formed the top of the hills, while at others it was present only as a cementing material for the gravel.

The next exposure, going south, in the Nueces section (except Peeler's, the exact correlation of which with Reynosa is somewhat uncertain) was found fully 80 miles from the Castroville locality, at Weedy creek, north of Oakville.

At a hill half a mile north of the creek we found the tufaceous limestone, interbedded with yellow clays and sand, passing into lavender clays at base. The section at the creek is as follows:

	Ft.
1. Reynosa limestone, white, siliceous, tufaceous, containing a few black grains and also including fragments of greenish sandstone, ...	3
2. Greenish, limy clay, rusted and containing seams of darker green color, ...	4
3. Highly calcareous clays or argillaceous limestone to creek, . .	15

Following Weedy creek to its junction with the Nueces, and that river to the "Falls," 3 miles below, the Reynosa was seen to have an extensive development, forming precipitous banks from 20 to 30 ft. high along the creek, although in many places it was eroded and the *Equus*-beds materials deposited in the hollows thus formed.

One mile south of Comanche creek there is a bluff showing light-gray sands interbedded with a heavy conglomerate, 20 ft.

The conglomerate contains pebbles and boulders of all sizes of materials derived from the underlying Eocene Tertiary, and has a calcareous matrix. At the Falls this conglomerate rests in the greenish-gray sands of the Eocene described in the section at mouth of Weedy creek. Numerous exposures of Reynosa materials were observed along the road between this point and Oakville.

They also appear in the bed of the creek northwest of Beeville, overlain by Pleistocene and recent deposits, where the irregular upper surface of the Reynosa was, for the most part, composed of gravel in a calcareous matrix. The pebbles were principally of limestone, many of them crystalline, with dendritic tracings of manganese. Only a few siliceous pebbles were found, but they did occur occasionally, varying in size

from 0.25 to 0.75 in. At this point the black sandy soil rested directly upon the Reynosa, but at other places the yellow clay is found between these two beds. Root-prints were observed in the Reynosa at one point, and also some of the overlying sandy clays, which, in addition to their calcareous concretions, showed strings and seams of limy material. From the best information I could obtain, the wells on the hills north of Beeville pass through about 40 ft. of this Reynosa rock, under which are found the sands and clays of the Frio beds.

The Reynosa also forms the underlying rock-material of the country until we begin the descent into the Nueces drainage-area, and the rolling country is largely due to its highly eroded surface. It is overlain, usually, by a slight deposit of either mottled or yellow clays, with lime, which often takes the form of replacements of rootlets. These clays contain many fragments of bone, but in them, at these localities, nothing was found well enough preserved for identification.

The upper part of the Reynosa contains the usual amount of gravel, with, perhaps, a little larger percentage of siliceous pebbles than ordinary, consisting of flint, silicified wood, agate and jasper, but still not aggregating more than 2 or 3 per cent. of the whole mass, which is composed of crystalline limestone pebbles, with dendrites.

The Reynosa of Lapara creek and Shipps ranch (Fort Merrill) have already been noticed in connection with the Lapara beds. Going south from Dinero toward Lagarto, the Reynosa makes its appearance in the road very shortly after the ascent of the "Bordas" is begun, and is seen in many places along the road before reaching Ramireno creek.

Ramireno Creek Section.—This section was made in the hills north of Ramireno creek, near the Dinero-Lagarto road, where a total thickness of about 75 ft. of materials can be seen:

	In.
1. Hard-pan, on top of hill, ...	2 to 3
2. Reynosa limestone.	
3. Brown, coarse-grained sandstone, underlain by laminated sands.	
4. Adobe, limy clay, green or black-mottled clays and sands, interbedded, and passing downward into sea-green and pink clays.	
5. Conglomerate of calcareous and siliceous pebbles in lime-matrix.	
6. Mottled clays.	
7. Same as No. 5.	
8. Brown sandstone, with siliceous pebbles (Lapara).	

The Reynosa include the materials of Nos. 1 to 7.

From this point, going south, the Reynosa is frequently exposed until we reach the line of the San Antonio and Aransas Pass railroad, running from Skidmore to Alice. Both sides of the Nueces valley is bordered by hills capped with these limestones, and they are shown by the railroad-cuts and by all streams and washes crossing them. In many places, however, they are overlain by the Pleistocene clays and recent sands. After leaving Driscoll, we saw no more of them (except from the bottom of a well at Collins) until we reached the vicinity of San Diego.

San Diego Section.—About 1.5 miles east of San Diego we found an outcrop on a slope just north of the wagon-road, where an excellent exposure exhibited the *Equus* beds, passing down to the contact with the Reynosa conglomerate, which was here underlain by a mottled, clayey sand like that at Lagarto, but with a larger proportion of sand and somewhat lighter in color.

Along San Diego creek, on the south and west of San Diego, as well as in Tarauchua creek, the Reynosa is well exposed, resting on sands, which may belong to the Lagarto beds or be a part of the Reynosa.

The tops of the hills are, by barometer measurement, 50 ft. above the bed of San Diego creek.

The Reynosa forms the top of the hills, and in its tufaceous form is quarried for building-purposes under the name of "adobe." This bed of limestone, with associated sands, clays and gravel, has a total thickness of 40 ft. at this locality. As always, it is extremely variable. In places, it seemingly contains no pebbles at all; in others, small siliceous pebbles are sparingly distributed; while at still others we have pockets, and even beds of conglomerate, so firmly cemented with the lime that it will break through the pebbles themselves. The pebbles are in part siliceous, and in part of crystalline limestone, with dendritic markings of manganese. At the base the gravel is heavier, and includes fragments and boulders of the underlying sands. The variability of the bed is further shown by the change from limestone to limy clays or limy sands along the same exposure, and it shows a tendency to cavernous weathering in places, while at others it weathers in perpendicular bluffs.

The lower 10 ft. of the San Diego section is made up of argillaceous sandstone, of yellowish-white color, with much lime. It is of variable hardness, some portions being much more indurated than others. The sand is fine and sharp, and its argillaceous character is apparent only on touching it with the tongue. The unconformity between this bed and the gravel of the overlying Reynosa is most apparent above the wagon-bridge on this creek, where the cavernous weathering of the Reynosa is exhibited.

In these sands, at this locality, we find boulders or segregations of the flinty or opaline rock, which has been described under the Lapara beds.

From San Diego north and west the Reynosa forms the surface-rock over the greater portion of the country between that point and the Bordas. It is covered by brown sands, and in places by Pleistocene deposits, but its presence is manifested by frequent exposures, and by a white or ashy-gray plant called by the citizens the ash-bush, or ash-weed, which in this area is an almost certain indication of the presence below it of the limestone, limy sands or limy clays.

Along the International and Great Northern railroad, the Reynosa is well exposed south of Moore station in the divides between the Medina and the Nueces, and also in the divide between the Nueces and the Rio Grande south of Webb.

Los Angeles Sections.—The scarp of the "Bordas," north and south of the Mexican National railroad, also gives a series of excellent exposures, which show some few differences from similar deposits at other localities. A section made at a hill 1 mile south of Los Ojuelos gave:

	Ft.
1. Arenaceous limestone or limy sandstone highly concretionary in places. The boulders are all more or less conglomeritic, with the usual dendritic crystalline limestone pebbles, together with some siliceous ones in a hard lime-matrix. These harder masses sometimes form pillars by the erosion of the softer material from around them, ...	6 to 8
2. Limy sands, with red sand; concretionary inclusions very similar in composition and appearance to the materials of the underlying bed. The body of the sand is flecked with red sand in places. These also form pillars by erosion, . . .	6 to 8
3. Heavy-bedded joint, clayey-sand, pinkish-brown in color, weathering in caverns. White on some surfaces, and checked or jointed, ...	15

Below this, as is seen at Los Ojuelos, we found another bed of limestone and the usual conglomerate underlying it. This rests on the sands and conglomerate of the Lapara beds, under which are yellow gypseous clays.

On the slope south of Los Angeles, a well was seen which passed through the tufaceous limestone, red clay and sand, with some gravel, to the Reynosa gravel in lime-matrix, a distance altogether of 35 ft. Below this was found the usual clay (Lagarto ?) from 75 to 100 ft. thick, and water was found in an underlying sand.

The presence of a hard-pan used for lime-making, at Carrizo Springs, has already been noticed. It is probably part of the Reynosa.

On the Nueces river, south of the Eagle Pass and Batesville road, the following section was observed, Nos. 2 and 3 being Reynosa material:

	Ft.
1. Brown silt,	
Unconformably on	
2. Yellow silt, with gravel and calcareous concretions, . .	10 to 12
3. Conglomerate, with yellow silt-matrix, ...	8 to 10
Unconformably on Eocene deposits.	

From this point to the road above mentioned, the yellow silt (No. 2) forms the surface-rock of the country, including even the higher hills.

On the Leona, north of Batesville, the Reynosa is well developed. It varies greatly in thickness, in the amount of lime it contains, in the presence or absence of gravel; and when the gravel is present, in the degree of induration. At times, the gravel is simply scattered through a loose calcareous sand, yellowish-white in color and weathering with a pitted appearance, due to the falling out of the pebbles; in other places the gravel makes up the bulk of the deposit and the sand is less abundant.

The more calcareous portions are in different localities a tufaceous limestone, a limy matrix, with sand and a few pebbles scattered through it, or a highly indurated conglomerate from 1 to 3 or more feet in thickness.

This Reynosa limestone forms the bed and banks of the Leona for several miles, beginning 3 miles above Batesville,

and is overlain by from 10 to 12 ft. of sand in places, and in others by the yellow silt with pebbles. The exposures continue along the river-course until the irrigated sugar-farm south of Uvalde is reached, and then along the road from there to Dillard's.

South of Dillard's we found a line of hills which were so completely drift-covered that nothing could be determined regarding the character of the rock-material composing them. In the drift there were boulders of flint and of purple quartzite, from 6 in. to 18 in. in diameter.

Extent of the Reynosa.—It may not be amiss to call attention to the fact, that the material of the Llano Estacado, which there occupies the same stratigraphical relations to the *Equus* beds as do the Reynosa beds in southern Texas, is lithologically identical with the limy phase of the Reynosa. These beds were observed by myself, at the top of the escarpment in Garza county, at the point marked "11" on map of the Llano Estacado, accompanying the *Third Annual Report of Geological Survey of Texas*, and also, just south of Big Springs, resting on the northern slope of the Cretaceous hills. Prof. Cummins has traced them over a large part of the Llano Estacado. We have no record of such deposits from the top of the Cretaceous plateau at Big Springs, between that place and the Nueces canyon, and so great is their similarity to Cretaceous materials that they might readily escape observation, unless one was looking specially for them. In the canyons, however, on the southern edge of the plateau, its presence has been reported by Taff and Leverett and others, and I have traced its continuation southward from the line of the Southern Pacific railroad to San Diego. Whether the beds were connected directly across this great plateau, or whether to the east or west of it, remains to be ascertained by further field-work. That they were connected is, I think, reasonably well established by their lithological identity, and their stratigraphical relations to the Blanco beds below and the *Equus* beds above.

Pleistocene.

The deposits which are considered referable to the Pleistocene include the *Equus* beds and connected deposits found

along the various rivers and creeks, the Coast clays and the later river-, creek- and surface-deposits, either of aqueous or aërial sedimentation. They consist of beds of gravel and conglomerate, sands, sandy and calcareous clays of various colors.

These deposits have not yet been studied closely enough to permit of proper differentiation. Usually they lie so flat, and the exposures are so rare, so disconnected and insignificant when they do occur, that very little work has been done on them, except in widely separated localities.

More than 50 years ago a series of fossils, collected by Mr. William Hough, of San Felipe, from certain beds in the banks of the Brazos river, were described by Dr. William Carpenter,* and these species were later referred to the Fauna of the *Equus* beds.

Subsequent to this, Dr. Leidy identified certain fossils from beds in eastern Texas, presumably of this horizon, as those species now regarded as belonging to the *Equus* beds.†

The announcement of the occurrence of the *Equus* beds in the region embraced in this report was made by Prof. E. D. Cope.‡ This was based on a number of fossils sent to him from the vicinity of San Diego by Mr. Wm. Taylor and Mr. G. W. Marnock, the larger number of the specimens having been found on Taranchua creek, a branch of San Diego creek. Other fossils taken from the same beds on the Brazos and on the streams in our area have been identified by Prof. Cope as belonging to this same stage. These beds form the second bottoms of the rivers south of the Eocene deposits.

Dr. Loughridge, in the *Tenth Census Reports*, refers all the Coast clays to the Port Hudson of Hilgard, and says of them, that, west of the Brazos delta,

> "the formation is prominently represented by heavy yellow and dark-colored gypseous clays, inclosing white calcareous concretions and some limestone beds, and in it have been found (at Lavaca) the fossil bones and teeth of mammoth quadrupeds."

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* *Amer. Jour. Sci.*, 2d series, vol. i., p. 244 (1846).

† *Proceedings Philadelphia Academy*, 1893.

‡ Prof. Cope's papers on these beds are as follows:

American Naturalist, 1884, where he describes a new species of mastodon (*M. Serridens*) from those beds.

Ibid., 1885. Identification of five species of horses from Nueces (Duval) county.

Ibid., 1889. Description of a new Glyptodon (*G. petaliferus*) from the same locality.

The identity of the second bottoms of our rivers with the Coast clays, or Columbia formation of McGee, has been asserted by that writer.*

The *Equus* beds are an earlier deposit than the Coast clays. The only contacts of any extent which I have observed seem to show that the Coast clays rest unconformably on them, and, lithologically, they have little or nothing in common. The evidence seems to indicate that the *Equus* beds here occupy a part of the time-interval between the emergence of the Lafayette and the Columbia submergence. On account of the fewness of satisfactory exposures, however, this matter must await further field-work before it can be finally determined.

Equus Beds.—At the close of the Neocene an elevation took place in this region, which made a dry-land area of the Reynosa, and the process of its erosion began. In the valleys and depressions thus hollowed out were laid down the ash-colored limy sands and gravel which constitute the *Equus* beds proper. In consequence, the base of these beds, as they follow the strongly eroded and extremely irregular surface of the Reynosa at the typical locality near San Diego, Duval county, include boulders and masses of the underlying limestone. Many pebbles occur through them, and in their lower portion they abound in fossil vertebrates.

The beds in which these fossils occur rest with great unconformity upon the Reynosa; indeed, there is no equal unconformity visible between any other two series of beds in the Cenozoic of Texas, so far as I have observed them.

The deposits consist of limy, conglomerate, ashy material, containing pockets of pebbles derived from the underlying Reynosa. The beds are without trace of stratification, except that here and there through them the calcareous matter appears as a line of nodules for a short distance, or a bed of pebbles will follow a straight line for several feet.

The beds are usually ashy-yellow in color, but lighter in places, and grade upward into a grayer and more sandy body, and then into a black soil. Their ashy appearance is one of their most distinguishing characteristics. When damp, they are easily dug into, but they become very hard on drying.

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* *Twelfth Annual Report of the United States Geological Survey.*

In the upper grayer material, bones are rarely found, but it carries instead a number of forms of land and fresh-water shells. However, no line of division can be drawn between the two portions, as the change is very gradual.

The thickness of the beds, so far as I have observed them, in no place exceeds 20 ft., and they appear to occur in detached or irregular basins, usually connected directly with some drainage-channel, present or past.

The first beds of this age observed in the Nueces section were at Benton, on Atascosa creek. From the conglomerate here, I took a portion of the lower jaw of a dog.

Similar deposits of gravel occur at intervals along the section until we reach Weedy creek, where numerous good exposures of the *Equus* and later beds occur. The section just below the crossing of the Campbellton and Oakville road is as follows:

	Ft.
1. Soil, ...	2
2. Laminated silt, ...	1
3. Mottled, sandy clay, with numerous land shells (*); this passes downward into, ...	2 to 8
4. Cross-bedded, ashy-gray sands; sands with pockets of gravel, lime-concretions toward top. Many fragments of bone, .	3 to 10
Unconformably on	
5. Reynosa lime and sand to creek.	

Similar beds occur along the Weedy to its mouth and down the Nueces for several miles. Below Oakville, these beds attain a somewhat greater prominence than they had above. The sections given in connection with the Lapara, pp. 964, 965, give an idea of their character. The fossils found were, as has been stated there, a mastodon tusk and numerous *Unios*.*

* Mr. Singley furnishes the following list and notes on the shells collected at this point:

Unio sp.? A number of very large *Unios*, too poorly-preserved for positive identification, were in the conglomerate. In some instances the valves were still attached; in others, the shell was dissolved, a cast of the interior proving conclusively that the shells were not drifted, but were in place. These shells were larger than any of the hundreds of Texas *Unios* from all parts of the State that have passed through my hands, and I am inclined to think it is *Unio undulatus*, Barnes.

Unio sp.? Two poorly-preserved left valves of a *Unio* from the gravel resemble some forms of *U. churnii*, Lea, but are much larger and heavier, and I do not care to refer them to that species with the insufficient material on hand on which to base a determination.

From the overlying silt, a mile or two above these beds, we found numerous specimens of *Unio berlandieri*, Lea. Mr. Singley says of it:

"This *Unio* was abundant above Bartlett's ford of the Nueces river in a dark-gray loam, and was seen at many places, either near the top of the river bluffs or on hills back from the river, where the surface had been eroded sufficiently to expose the shells. These shells were not taken to their present station by Indians using them as food, as the deposits are too large, too numerous, and show that they are in place, in an old lake-bed. The species is still found living in the river."

In the second section made on Lapara creek, p. 965, No. 2 may be taken as representing the *Equus* beds, as it contained fossils referable to that horizon. A similar bed occurs on Hog Hollow, on the west side of the Nueces, overlying the Neocene grit and sandstone.

Penitas creek, on the Lagarto-Driscoll road, also shows exposures of *Equus* beds.

We have at the base a mottled, greenish-gray and red limy clay with manganese, not, however, overlain by limy clay or sandy lime, as at Lagarto, but followed immediately by the ashy-yellow clays of the *Equus* beds. At the bottom of this bed there is frequently a deposit of gravel, from a few inches to a foot in thickness. The pebbles are chiefly calcareous, and also occur throughout the sandy, limy clays above. The *Equus* bed here grades upward through a red-mottled sand into a black soil.

On San Fernando creek, between Driscoll and Alice, these beds were found forming the bank of the creek.

The other exposures on Penitas creek, on the Lagarto-Wade road, have already been given in connection with the Lagarto clays.

Coast Clays.—The Coast clays and later deposits were not examined, in the work done in this region, in sufficient detail to enable me to give any particulars regarding them, further than appear in connection with the sections already given.

The Blake Stone- and Ore-Breaker: Its Invention, Forms and Modifications, and its Importance in Engineering Industries.

BY WILLIAM P. BLAKE, DIRECTOR OF THE ARIZONA SCHOOL OF MINES, TUCSON, ARIZONA.

(New Haven Meeting, October, 1902.)

CONTENTS.

INTRODUCTION.

The Blake Stone-Breaker Prize.—Among the recent benefactions to the Sheffield Scientific School of Yale University is the institution by the heirs of Eli Whitney Blake, formerly of New Haven, of a prize to be known as the Blake Stone-Breaker Prize.

By the terms of this gift, the prize is to be not less than $50 in gold coin, and is "to be awarded from time to time to the author of any treatise deemed worthy of such award on some subject connected with mining or civil engineering, and preferably with some branch of those pursuits in which the use of broken stone, or ores, is a material feature."

The prize, though it is to be given preferentially for work of students, graduate or undergraduate, of the Sheffield Scientific School, may, also, be awarded to any other person for meritorious achievement.*

It seems appropriate, therefore, to call attention at this time to the importance of the Blake stone-breaker as an economic and industrial invention, especially valuable in mining and metallurgic work, and, in connection with such a review, to give a brief biographical notice of the inventor, to whom not only

* SECRETARY'S NOTE.—Since the reading of this paper, the author has received for it the "Blake Stone-Breaker Prize."—R. W. R.

the engineering profession in all its branches, but the world at large, is so considerably indebted.

Great Labor-Saving Inventions.—Great labor-saving machines have ever been most potent factors in the onward march of civilization. By their amelioration of the conditions of life they have largely promoted intellectual and æsthetic development.

In the long list of wealth-producing inventions by which civilization has been rapidly advanced in the last two centuries, we note specially the spinning-jenny of Arkwright; the steam-engine of Watt; the steamboat of Fulton; the cotton-gin of Whitney; the pneumatic process of Bessemer; the reaper of McCormick; the sewing-machine, the Westinghouse pneumatic brake; the telegraph and the telephone.

To this honor-list I would now add the Blake stone-breaker, as a labor-saving machine of the first order, which for originality, simplicity and effectiveness, has justly been regarded by experts as almost unique.

As such inventions, instead of repressing and supplanting labor, have widened its fields, and have given increased opportunities for occupation, the inventors may rightfully be called not only "Captains," but Fathers, of Industry.

The Blake breaker is well known over the entire globe, wherever modern enterprise has penetrated. The crunching of its powerful jaws may be heard in mining-camps from Alaska to Panama; from Sweden to South Africa. Wherever we turn, whether as architects or civil engineers, as miners, metallurgists or travelers, we find that the stone-breaker has been a most important adjunct of civilization, and realize that broken-stone has become a staple necessity of modern industrial progress.

I. Biographical Notice of the Inventor.

Eli Whitney Blake, the inventor of this machine, was born in Westboro, Worcester county, Mass., January 27, 1795. His father was a direct descendant of William, of Dorchester, Mass., 1630, and his mother a sister of Eli Whitney, the inventor of the cotton-gin, and the first to inaugurate, or to establish, the uniformity system in manufacturing in the United States. Mr. Blake was graduated at Yale in the class of 1816,

and began the study of law in the then famous school of Judge Gould at Litchfield, Conn., but gave up that profession at the request of his uncle, Eli Whitney, who needed his assistance in erecting and organizing the works at Whitneyville, near New Haven, for the manufacture of firearms for the United States Government.

After the death of Eli Whitney in 1826, the business was carried on by Mr. Blake and his brothers until 1836, when they established the business of manufacturing hardware at Westville, in the suburbs of New Haven.

In the year 1852 Mr. Blake was appointed a member of a committee to superintend the macadamizing of Whalley Avenue, leading to Westville. His attention was thus directed to the great difficulty and expense of breaking road-metal by hand, and to the need of a machine for the purpose. The problem was a very old one, but no successful solution had ever been found. The requisite conditions were carefully considered. The character of the rock to be broken, its fracture, and the force required to break it were first ascertained. Then a plan for obtaining the great force required with the least possible motion and friction was devised. The machine and all its parts was conceived and arranged in the mind of the inventor, even to the calculation of the necessary strength and weight of the different parts, before a machine was constructed. It was thus the product of a scientific mind aided by practical skill and experience.

The practical working of the first machine fully realized the expectations of the inventor, the effect produced being as anticipated, not only with trap-rock, but with a variety of unyielding ores and minerals. It was an entire and gratifying success. Patents were granted for the machine in the United States and other countries in 1858. The United States patent was extended in 1872 for seven years, and expired in 1879, so that to-day the stone-breaker is freely made and used without royalty in all parts of the world.

Mr. Blake's abilities and acquirements in the field of mathematical and physical science were of a high order. He contributed many valuable papers to scientific journals on various subjects. Some of these were collected and printed in 1882, in a small volume, entitled, *Original Solutions of Several Problems*

in Aëro-dynamics. These papers, which were the result of original research and experiment, treat of the laws which govern the flow of elastic fluids through an orifice; the propagation of pulses in elastic media; the mode of expansion of elastic media, and the velocity and transmission of sound. This compilation, which included some new investigations, was undertaken after his eightieth year. He was one of the founders, and for several years the President, of the Connecticut Academy of Arts and Sciences. He was a trustee of the Hopkins Grammar School for several years, and in 1879 received from Yale Univesrity the honorary degree of LL.D. He died in 1886, at the age of 91 years.

II. Former Methods of Breaking Stone.

Up to the date of the invention of the rock-breaker, stone for road-metal was broken by hand, with the aid of a hammer having a long, pliant handle, and a round, ball-like head, illustrative drawings of which may still be found in standard dictionaries of engineering.*

Breaking stone by hand has always been slow, monotonous, tedious work; an occupation suitable to convicts, tramps or denizens of the poor-house. And even now convicts and tramps are occasionally so employed, as, for example, at Buffalo, N. Y.†

Ragging and Spalling.—Breaking stone by hand was a common sight a few years ago along the macadam roads of England, but much of this work is now done by portable machine stone-breakers.

So, also, in the mechanical preparation of ores, breaking by hand was common, and is still required at the tin-mines of Cornwall, and in some other mining-regions, where hand-sorting is essential. But by means of the stone- or ore-breaker in

* Spon's *Dictionary of Engineering,* viii., 2784, 1874. See, also, Knight's *American Mechanical Dictionary.*

† Prisoners in the penitentiary for short terms, being forced to work on the highways, have been utilized at Buffalo in breaking stone by hand. It is noteworthy that the effect on the convicts has been beneficial. A number of men who were in a weakened condition from excessive drinking became strong and healthy and able to do a hard day's work. Several men reformed. Another good effect was the decrease in the number of tramps in the streets. They avoided Buffalo.

most instances the work can be much expedited and cheapened. The broken-up ore being received, either upon a revolving table or upon an endless belt, is easily picked over and assorted.

Much of the breaking by hammers in Cornwall is done by women. A mass of ore upon the ground is held in place by the ball of the foot while subjected to a sharp and quick blow from the hammer. The first rough breaking, known as "ragging," requires a hammer or sledge from 6 to 8 lb. in weight, and the second operation, known as "spalling," requires a hammer weighing about 1 lb.

Cornish Rolls.—In ore- and rock-breaking, up to the time of the invention of the Blake stone-breaker, besides the ragging and spalling by hand, ores were roughly crushed by rolls, generally known as Cornish rolls, with the construction and use of which we are all familiar. While this is a very effective and useful machine when new and carefully fed, the product lacks evenness and uniformity in size. A large mass of hard rock fed to the rolls separates them to such a degree that smaller rocks drop through without being acted on, and so escape crushing. The space between the rolls varies with the size and resistance of the masses fed in to it; with the rock-breaker, the greatest width of the opening is invariably the same and is predetermined at will. In the rolls there is great friction and wear by rubbing and sliding of rocks upon the revolving crushing-surface, resulting in the rapid wearing-down of the medial portion of the face of the rolls, by which a large space is left between them, and the effective operation of the machine is quickly impaired.

III. The Construction of the Blake Stone-Breaker.*

The construction of the stone-breaker is best described in the language of the inventor:

"As respects its principles, or its essential characteristics, it consists of a pair of cast-iron jaws, one fixed and the other movable, between which the stones are to be broken, having their acting faces nearly in an upright position and conver-

* One of the earliest printed descriptions of this invention was published by the writer of these pages in January, 1861, under the title of "A New Machine for Breaking Stone and Ores," *Mining Magazine and Journal of Geology*, second series, vol. ii., No. 1, p. 50.

gent downward one towards the other in such manner that, while the space between them at the top is such as to receive the stones that are to be broken that at the bottom is only sufficient to allow the fragments to pass when broken to the required size; and giving to the movable jaw a short and powerful vibration through a small space, say one-fourth of an inch, more or less. By means of this form and arrangement of the jaws, and this motion of the movable jaw, when a stone is dropped into the space between them it falls down until its further descent is arrested between their convergent faces: the movable jaw, advancing, crushes it, then receding, liberates the fragments and they again descend, and if too large are again crushed, and so on, until all the fragments, having been sufficiently reduced, have passed out through the narrow space [between the jaws] at the bottom."

The claims made by the inventor in his application for a patent, which was granted June 15, 1858, and was reissued January 9, 1866, were as follows:

"What I claim as my invention in the herein-described machine, and desire to secure by Letters Patent, is:

"I. The combination in a Stone-Breaking Machine of the upright convergent jaws with a revolving shaft and mechanism for imparting a definite reciprocating movement to one of the jaws from the revolving shaft, the whole being and operating substantially as set forth.

"II. The combination in a Stone-Breaking Machine of the upright movable jaw with the revolving shaft and fly-wheel, the whole being and operating substantially as set forth.

"III. In combination with the upright converging jaws and the revolving shaft imparting a definitely limited vibration to the movable jaw, so arranging the jaws that they can be set at different distances from each other at the bottom, so as to produce fragments of any desired size."

These claims were approved and allowed by the Board of Examiners-in-Chief on appeal, after a full and careful investigation.

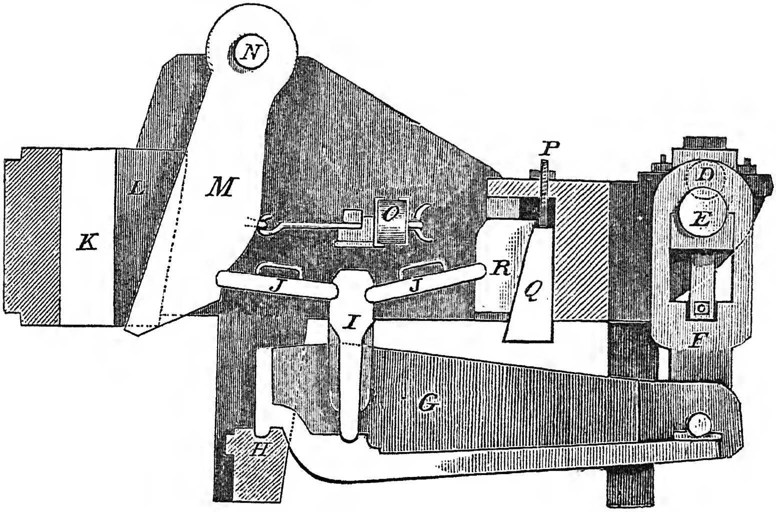
The Lever-Pattern.—One of the earliest forms of the machine, known generally as the "Lever-Pattern," is represented by Figs. 1, 1*a* and 2.

Fig. 1 is a side-view, or vertical, longitudinal section through the center of the machine, showing one-half of the heavy, cast-iron frame in the background. Fig. 1*a* is a perspective view of the same machine.

Fig. 2 represents the machine as seen from above, and shows the two fly-wheels and the opening between the jaws. The lettering corresponds in both figures.

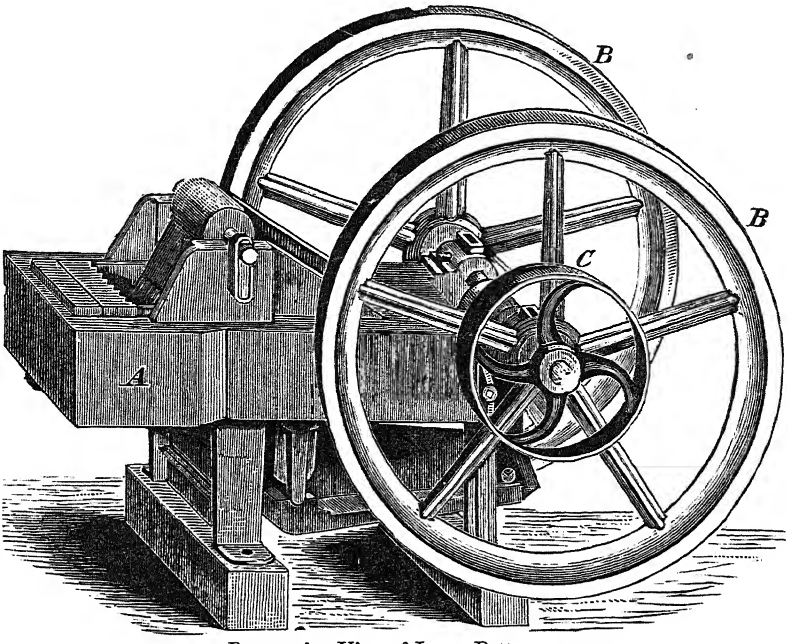
The operation of the breaker is evident from the inspection of these figures. It is driven by a belt upon the pulley C.

Fig. 1.



Sectional View of Lever Pattern.

Fig. 1*a*.



Perspective View of Lever Pattern.
A, main frame ; BB, fly-wheels ; C, pulley.

The revolution of the crank-shaft D E alternately raises and lowers the pitman F and the long arm of the lever G, by which the vertical I is made to rise and fall between the toggles J J, thrusting the movable jaw M forwards towards the

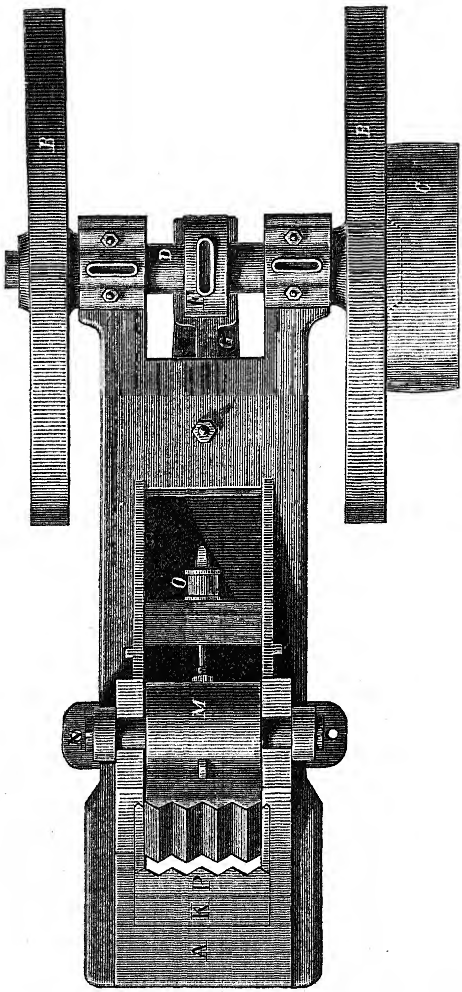


FIG. 2.

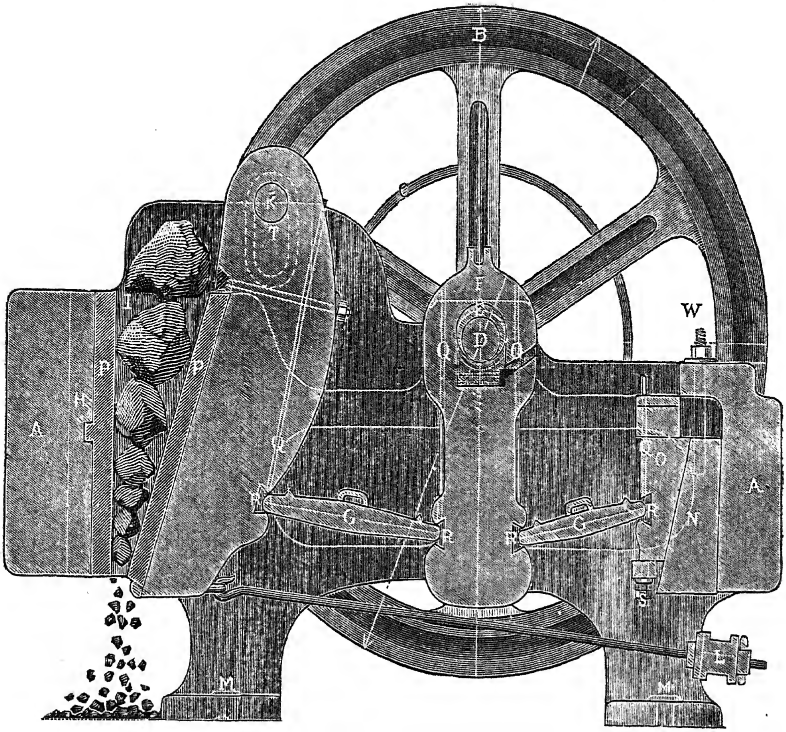
Lever Pattern as seen from above.

B, D, E, fly-wheel, shaft and crank; F, pitman; G, lever; H, lever-bearing; I, vertical; J J, toggles; K, fixed jaw; L, cheek; M, movable jaw; N, jaw-shaft; O, rubber-spring; P, plates; Q, wedge; R, toggle-block; W, wedge-nut.

fixed jaw K. The return-movement of the jaw is effected by a rubber-spring O, which is compressed when the jaw is thrust forwards. At the back-end of the frame an arrangement of two wedge-shaped blocks R and Q (seen only in the section, Fig. 1)

permits of shortening or lengthening the distance in which the toggles move, thus determining the extent of the throw of the movable jaw, varying the size of the opening at the lower or discharge-end of the jaw, and also taking up the wear on the ends of the toggles and other parts.

Fig. 3.



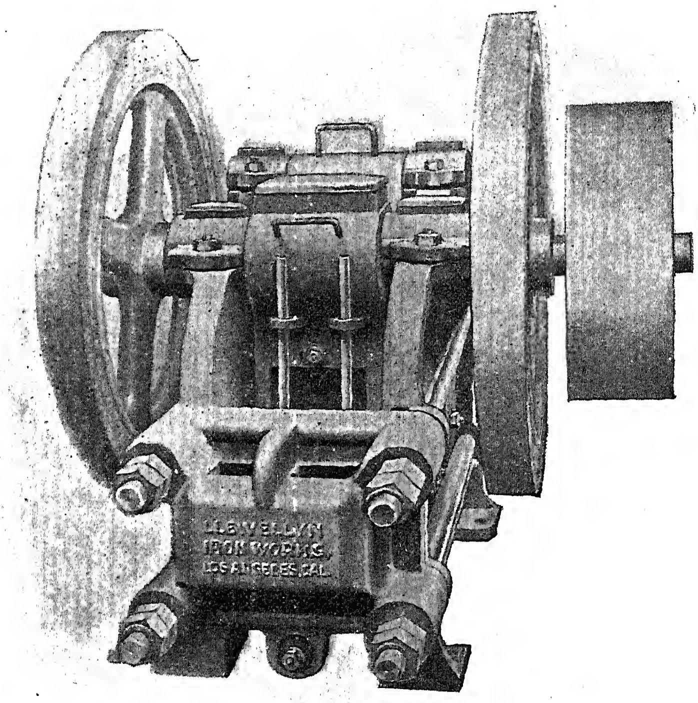
The Eccentric Pattern, Sectional View.
A A, main frame; B, fly-wheels; C, driving-pulley; D, crank-shaft; F, pitman; G G, toggles; H, fixed jaw; I, cheek; J, movable jaw; K, jaw-shaft; L, rubber-spring; N, wedge; O, toggle-block; P P, jaw-plates; Q Q, tubes for oil to bearings; R, toggle-bearings; W, wedge-nut.

This pattern has always been a very effective and popular form of the breaker, and is by some, to-day, preferred to any other. The lever-machine is, however, heavier and more cumbrous than one in which the lever is dispensed with and the pitman F operates the toggles directly.

The Eccentric Pattern.—This form is shown in section in the above illustration, Fig. 3.

This is now the prevailing, and may be said to be the standard, form of the Blake stone-breaker. It has undergone some minor modifications of form and construction by different makers, but remains essentially the same as it left the hands of the inventor. It was early introduced into England by Mr. Marsden, the former employé and agent of the manufacturers, who built the machines for England at Leeds.*

Fig. 4.



Perspective View of Eccentric Pattern, Showing Frame and Steel Rods.

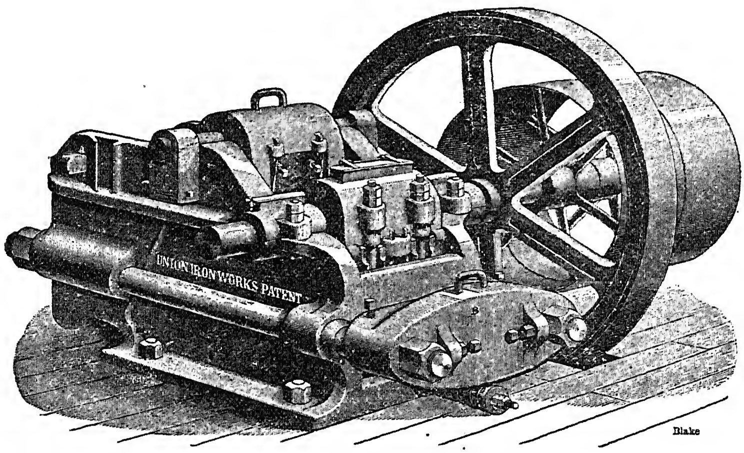
Fig. 4 gives a good perspective view of the construction of a frame, in which the strain is received chiefly upon steel rods, as now made by the Llewellyn Iron-Works, Los Angeles, Cal. It represents the usual eccentric pattern, as seen from the rear end.

* Mr. Marsden was sent to England by the firm of Blake Brothers to introduce the rock-breaker there. He had great success; became a popular and highly-respected citizen of Leeds; and was elected mayor of the city.

Fig. 5 illustrates the construction of the rock-breaker of the eccentric type as now built by the Union Iron-Works, San Francisco. It shows the rear end of the frame and the arrangement of the bolts, the top of the pitman and of the swinging jaw. This form is made in two sizes, 8 by 12 in. and 10 by 16 in.

The immense strain upon the frame of the breaker, especially in the larger sizes, necessitates a great thickness and weight of cast-iron; the frame of the 20- by 12-in. machine weighing no less than 10,000 lb. This great weight is avoided by many manufacturers by throwing the stress upon

Fig. 5.



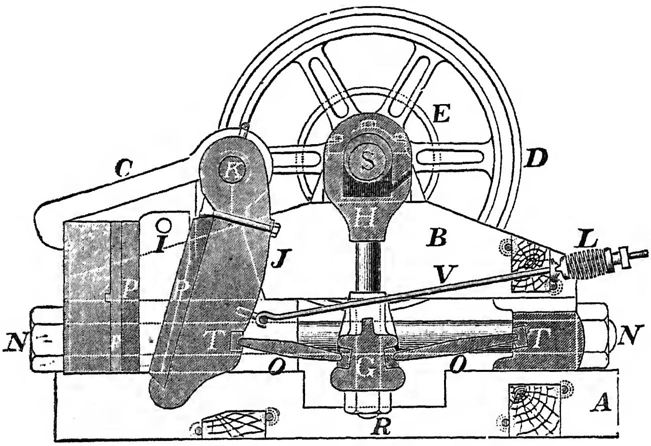
The Union Iron-Works Pattern.

wrought-iron or steel rods passing through, or along side of, the cast-iron frame, which secures a lighter frame with equal or greater strength than when made wholly of cast-iron.

The Challenge Pattern.—In the "Challenge breaker," a form designed and manufactured by Theodore A. Blake, the sides of the frame are replaced by timber, the ends of the frame, only, being of cast-iron and connected by heavy rods of steel in the line of greatest tensile stress, near the bottom of the jaws, as shown in Fig. 6. This form of breaker is sectional, so that it can be taken apart for convenience of transportation; the weight of the heaviest piece, in the 15 by 9 in. size, being only 2,400 lb.

The following description of the "Challenge," understood to be from the pen of Prof. H. M. Howe, which appeared in the correspondence of *The Engineering and Mining Journal*, N. Y., of November 17, 1883, in regard to Metallurgy and Engineering, at the Boston Fair, so well describes the points of difference between the "Challenge" and the "Eccentric" pattern crushers that it is given in full.

FIG. 6.



Section of Challenge Pattern.

A, lower timber-frame; B, upper; F, fixed jaw; J, swing-jaw; K, jaw-shaft; C, clamps; I, cheeks; P P, jaw-plates; N N, main tension-rod nuts; V, spring-rod; R H, pitman; R, pitman rod-nuts; G, pitman toggle-block; O O, toggles; S, main eccentric shaft; D, fly-wheels; L, spring on spring-rod; H, pitman half-box; E, pulley; T, main toggle-block.

The letters used in the following description refer to the sectional view, Fig. 6.

"This improved form of our old friend, the Blake crusher, has such marked advantages over the older form that it is likely to supersede it. The form of Blake crusher, now called the 'Eccentric,' consisted of a fixed jaw *F*, and a moving jaw *J*, actuated by a toggle-joint, all of which were contained and rigidly supported by a very strong cast-iron frame or box. The upper end of the movable jaw was fixed, and the lower end was moved by a toggle-joint driven by a pitman *R H*, somewhat as shown in the accompanying cut. Of course, when the pitman ascended, forcing the movable jaw toward the fixed one and crushing the ore between them, there was a tremendous longitudinal strain in the cast-iron frame which contained the two jaws, and against the ends of which the fixed jaw and the outer toggle pressed violently. To resist this pressure, the frame needed great strength, and consequently a large cross-section and great weight per unit of length. To avoid excessive weight, the frame was made short, which necessitated making the toggles *O O* short also. Now the proportion of the downward

pressure of the pitman, which is resolved into horizontal pressure against the jaw *J*, depends on the angle which the toggles make with each other. If they are nearly parallel with each other, most of the downward pressure of the pitman will be resolved into downward pressure on the bearings *T T*, and but a small portion into horizontal pressure; of course, economical working demands that as much as possible of the power be resolved into useful horizontal pressure and as little as possible into vertical pressure, which is simply rigidly resisted by fixed parts of the machine. Now, if we suppose, for simplicity, that in every case the toggles are, approximately, in a straight line with each other at the end of the pitman's downward stroke, it should be evident that, for a given length of stroke of the pitman, the longer the toggles are, the less will be their inclination to each other at the beginning of the stroke. Thus efficiency demands length of toggles, which in turn requires excessive length and weight of the containing cast-iron frame.

"In the 'Challenge' crusher, which is represented in Fig. 6, the tensile strains are taken up, not by weak cast-iron, with its puny strength of, say, 20,000 lb., perhaps seriously weakened by cooling strains, but by light steel bolts, many times as strong per unit of weight. The upper end of the jaws is held together by the powerful steel strap *C*, and the bottom of the fixed jaws is held firmly by the strong steel bolts *R*, to the block *B*, against which the outer toggle presses. These bolts are in the plane of the toggles, thus concentrating the material near the line of strain. This arrangement permits us to increase the length of the toggles, and thus to get high efficiency, and at the same time to get a very much lighter machine. The upward pressure of the eccentric shaft *S* is taken up by the wooden beams *A A*. It is evident that, as the toggles wear, not only will the opening between the jaws, but also the obliquity of the toggles to each other, be increased; and as that obliquity increases, so will the horizontal travel of the jaw increase."

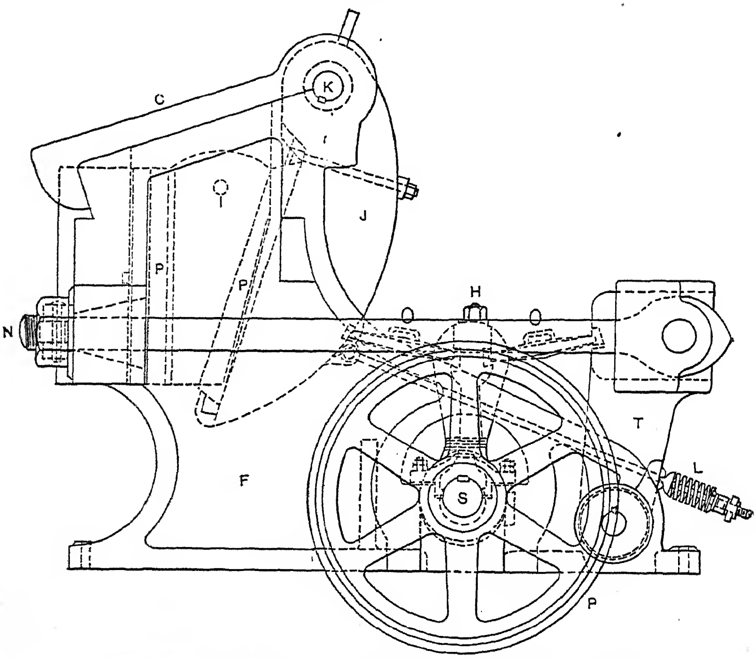
The Monarch Pattern.—In the form of breaker known as the "Monarch," Fig. 7, the main frame is of cast-iron, but the tensile strains due to crushing are wholly upon wrought metal. The rear toggle-block instead of being a rigid part of the frame is pivoted at the bottom. The main shaft and eccentric are placed below instead of above the toggles. These breakers, as the name indicates, are made of great size and capacity. The weights of three different sizes are, respectively, 45,000, 50,000 and 56,000 lb., and to drive them, from 25 to 30 H.P. are required.

The Multiple-Jaw Pattern.—In the preparation of ores for concentration, especially if the ores are intended for jigging, it is usually necessary to obtain much smaller fragments than are yielded by the operation of the standard patterns of the breaker, before described. To meet this need, Mr. Theodore A. Blake has devised a machine with several parallel jaws, the construction of which is shown by Figs. 8 and 9.

This machine will receive the product of the ordinary sin-

gle-jaw Blake crusher, and crush down to one-eighth of an inch or finer if required. The principle of crushing is the same as in the Blake single-jaw crusher, *i.e.*, by simple pressure between upright convergent faces. Instead of a single jaw, there is a series of jaw openings—in the illustration, four—each opening having a receiving capacity of 20 by 2 in. The main jaw has a reciprocating motion, given to it by

Fig. 7.



The Monarch Pattern. Side Elevation. Sectional View.

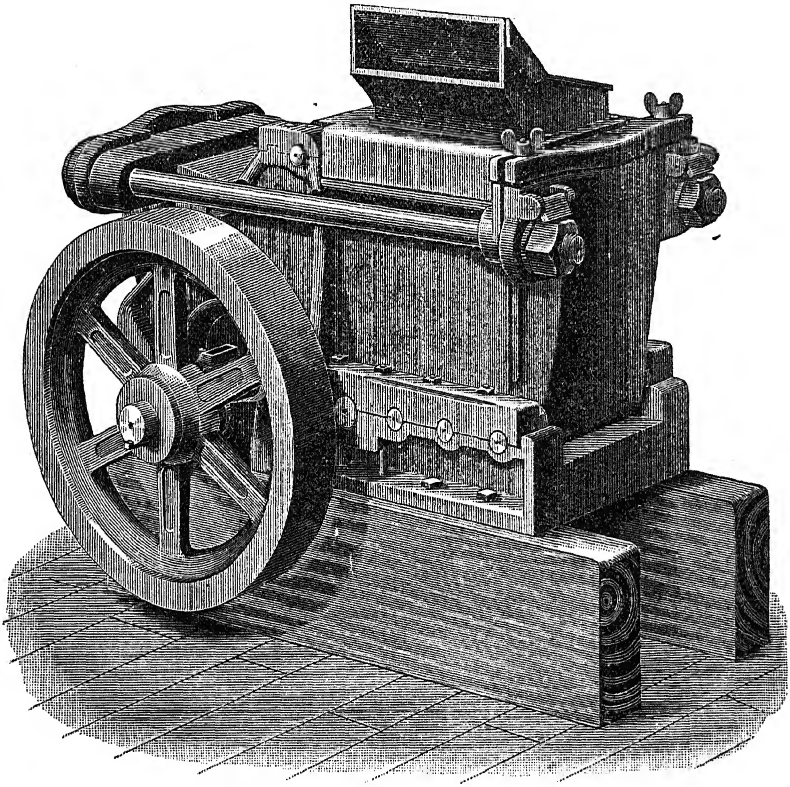
C, clamps; K, swing-jaw shaft; J, swing-jaw; N, tension-rod; T, toggle-block; O O, toggles; S, main eccentric shaft; P P, jaw-plates; I, cheeks; F, main frame; H, pitman; L, spring on spring-rod.

means of a toggle-joint, pitman and eccentric shaft, as in the ordinary crusher. The motion and pressure necessary to crush the material are transmitted to each succeeding jaw *through the material* itself. The multiplicity of jaws, besides giving a large discharging capacity, operates as a safety-provision. In case a piece of iron or steel should get into one of the jaw openings, the stroke which that opening would have is taken up by the others and no breakage or stoppage ensues.

In the illustration shown, each jaw having a receiving-capacity of 20 by 2 in., and there being four of them, it is evident that the capacity of the machine is equal to that of a single-jaw crusher with a receiving capacity of 80 by 2 in.

Crushing can be carried by multiple crushers to one-eighth inch, or even finer, with far greater economy than by any other

FIG. 8.



The Multiple-Jaw Pattern. Perspective Elevation.

method. These crushers are intended to be used "in series" precisely as in the case of "Rolls," for which they are an invaluable substitute. The jaw-faces are strips of steel and can be inverted when worn, or wholly renewed in a few minutes, thus causing but little or no interruption to the work.

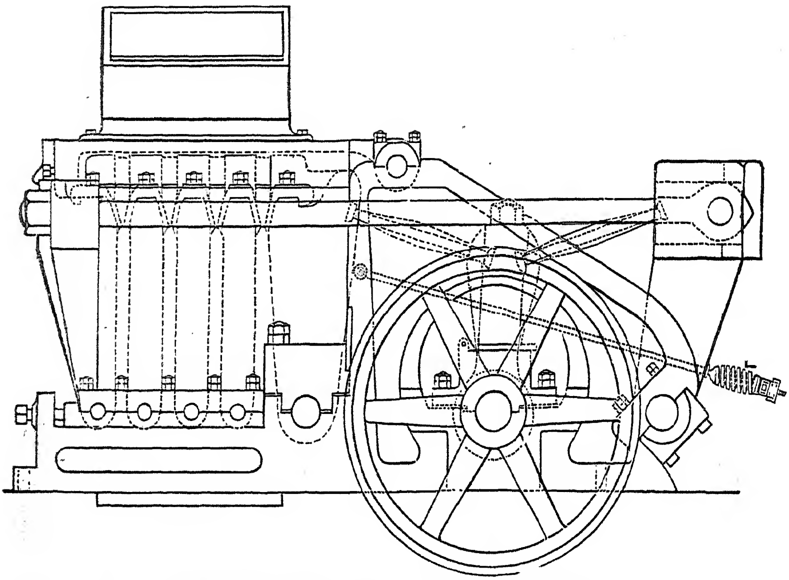
The product for purposes of concentration will be found to be unequalled; a smaller percentage of "fines" being made than by any other method of crushing.

For preliminary crushing, preparatory to further comminution, they will be found to be far more economical than rolls or any other known device.

They will do the work for which they are intended with as much ease and certainty as the ordinary Blake single-jaw crusher, and with even greater economy per ton of ore crushed.

Machines can be made of almost any size and required capacity to suit various conditions of use or requirements.

FIG. 9.



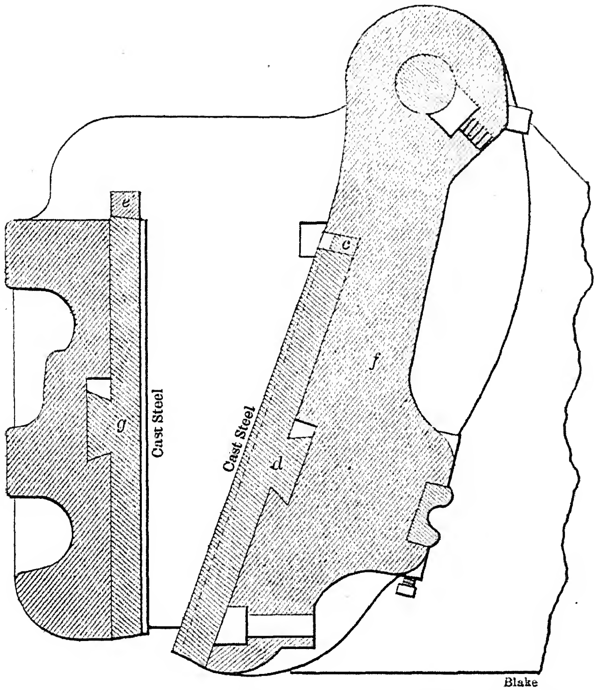
The Multiple-Jaw Pattern. Sectional Elevation.

Movable Dies for Jaws.—In the original rock-breakers no provision was made for a movable face-plate, or die, for the oscillating jaw, to receive the wear, so as to be discarded when worn and replaced by another. The jaw at first was cast in one piece, but the corrugated face was chilled. A movable die was not so important in the Eastern and Central States, where breakers were not far from foundries, and the cost of transportation of worn-out jaws was not great; but it was far different upon the Pacific coast, and the necessity of providing a movable face-plate, or die, for the oscillating jaw, early became apparent. This want was supplied by the writer for the California-

made machines at the Union Iron-Works of San Francisco, where the first patterns and castings were made.

Fig. 10, a sectional representation of mouth and the fixed and swinging jaw of the rock-breaker, shows the form of the jaw-plates, or dies, *g* and *d*, as now made by the Union Iron-Works, San Francisco. These movable dies are made of cast-steel. They are reversible and are held in place by the dove-tail lugs and the locking-keys *e* and *c*.

FIG. 10.



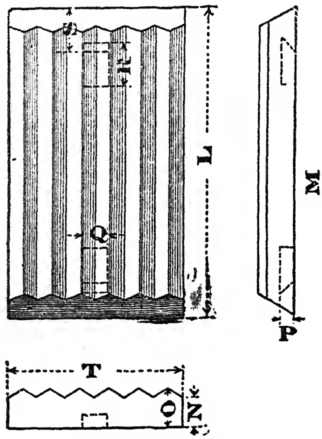
Jaw and Jaw-Plates of Cast-Steel as made at the Union Iron-Works. The Jaw-Plates are Reversible.

The form of the die was such that it could be reversed, end for end, and could be securely attached to the front of the ponderous oscillating jaw. Such movable, reversible jaw-plates, or dies, are now a recognized necessity in all rock-breakers, just as shoes and dies are required in stamp-mills and new shells upon rolls.

These dies are so constructed by the insertion of wrought-iron

strips in the castings that a true plane-surface bearing can be secured by planing, rendering the use of white-metal bearings unnecessary.

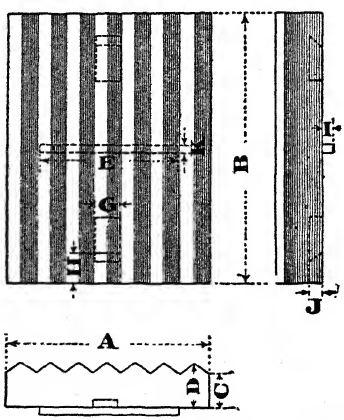
Fig. 11.



Movable Jaw Die.

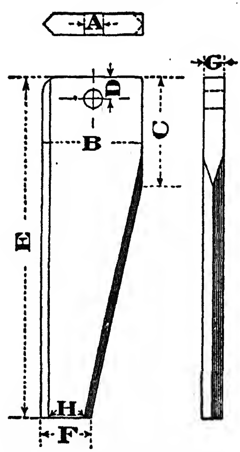
Fig. 11 shows the form of hardened jaw-plate, or die, for the oscillating jaw, as manufactured by the Allis-Chalmers Co.

Fig. 12.



Fixed Jaw Die.

Fig. 13.



Cheek-Plates.

for the Blake rock-breaker. The figure gives a front-, side- and end-view; the front- and end-views show the corrugations. These dies are reversible, end for end, and are easily attached to the jaw by means of lugs and slots in the castings.

Fig. 12 shows the form of the fixed jaw, which is a plane rectangular block with a corrugated face, and is also reversible, end for end.

Cheek-Plates.—In order to avoid the wear of the frame of the breaker at the sides or ends of the opening between the jaws, movable plates are provided, known as cheek-plates, which on becoming worn are renewed at small cost. Fig. 13 shows the form of these plates by a front-view D B H, an edge-view G, and an end-view, or section, A.

IV. The Capacity of Blake Breakers.

The capacity of all the Blake breakers is determined by the size of the opening between the jaws at the top. This opening, which may properly be called the *mouth*, varies in the smaller sizes from 2 or 3 in., in the laboratory breaker, up to from 30 by 12 in. to 30 by 18 in. in the Monarch, and to 24 by 24 in. in a still larger and exceptional size, specially made by the inventor for the Calumet & Hecla Co., Lake Superior, which takes in masses of copper conglomerate 20 in. or more in diameter, and breaks them up sufficiently to permit the pieces to be fed to breakers of ordinary capacity.

The 15 by 11 in. size may be termed a medium coarse breaker—it will receive rocks 11 in. thick and break to 3 or 4 in. It is used by miners and, to some extent, at smelting-furnaces.

The 15 by 13 in. is what is termed a coarse or preliminary breaker. It is made, also, with a 24 by 18 in. mouth. It is used chiefly at copper-mines. It receives large masses of ore 15 by 13 in. thick, or 24 by 18 in., and breaks them to 6 or 8-in. pieces, which are thus prepared for further reduction by the smaller breakers.

The production in tons in a given time, of course, depends not only upon the hardness and weight or gravity of the material broken, but upon the size to which it is broken, and the rate of feeding. The size of the broken stone or ore is determined by the distance the jaws are set apart. In a 15- by 9-in. machine, when the jaws are set 1.5 in. apart at the bottom and the machine is run at its proper speed, and diligently fed, it will break 7 cu. yards of quartz per hour, or nearly 10 tons. This large product often induces the selection of a smaller machine, losing sight of the fact that the usefulness of a breaker

is determined by the size of the rocks it will receive, rather than by the amount which can be broken by it. The largest size of the Monarch form is capable of receiving and crushing a rock measuring nearly 30 in. in length and 18 in. in thickness. The medium-sized breakers, known as the 15 by 7 in. and the 15 by 9 in., are the sizes best adapted to general purposes and for breaking stone for Macadam roads and ballasting railroads and for concrete. They are also used extensively at smelting-furnaces, also at copper- and other mines, to take the product of the coarse breakers and reduce it to proper size for feeding under the stamps.

Position and Feeding of Breakers.—The mouth of the breaker should not be raised above the level of the feeding-floor, but should be on the same level, so that rocks, or ores, may be easily pushed forward into the opening without being lifted. Breakers for effective service in the large way are not provided with hoppers to receive the material to be broken; the cheeks and the upper part of the oscillating jaw being sufficient to receive and hold the rock. It is necessary that the mouth should not be filled before starting a breaker. Feeding is deferred until the usual speed is attained.

In respect of feeding the rock-breaker, and in regard to the amount of ore broken, the following is pertinent, from the published memoir by John Hays Hammond, E.M.*

"The rock-breaker is placed directly below and in front of the coarse ore-bin. The chute leads from the gate of the bin into the jaws of the rock-breaker. The gate opening from the coarse ore-bin into this chute is worked by rack and pinion. By this gate the supply of ore delivered to the rock-breaker is controlled. This arrangement insures an almost continuous supply of ore to the rock-breaker, thereby greatly increasing the capacity of that machine. In most mills the coarse ore is discharged over the grizzly on to the rock-breaker floor, where it is picked up by the man who feeds the rock-breaker. This not only occasions unnecessary labor, but decreases the capacity of the rock-breaker through failure to keep it constantly supplied with ore. At the North Star mill [Grass Valley, Cal.], where the above arrangement has been introduced, one rock-breaker (15 x 9 in.) crushes from 30 to 40 tons of hard rock in from 5 to 7 hours, effecting a saving of wages of two or three men, as compared with the labor required in mills arranged according to the system generally adopted. As further evidence of the comparatively unintermittent working of the rock-breaker, it requires 12 H.P. instead of 8, as is usually computed for machines of the above

* "The Milling of Gold-Ores in California," *Rept. of the State Mineralogist of California*, viii., 1888, p. 699.

dimensions." . . . "Where the fall permits, it will be found advantageous to have two sets of rock-breakers, the first crushing coarse and delivering the crushed ore to the second set of rock-breakers, to be crushed finer than is the present custom. This would greatly increase the capacity of the stamp. The rock-breakers are adjusted to crush the ore to pieces smaller than from 2 to 3 in. The rock-breaker shoes and dies last from 6 to 8 months. When of steel, they wear about twice as long."

At the Copper Cliff mine, Sudbury, Ontario, where the Blake breakers were used to break the ore for the roasting-heaps, the 15- by 9-in. machine had a capacity of about 20 tons an hour of ore, broken so that the largest pieces passed a 4-in. ring; the medium size a 1.75-in. ring, and the fines through a screen of 0.75 in.*

In a description by A. J. Bowie, Jr., of the Father de Smet gold-mill,† where the 15- by 9-in. size breakers were used, it is stated that the capacity of the mill was from 4400 to 5400 tons of quartz, and, with the addition of 2 more breakers, the capacity was increased to 6200 tons of quartz, and to 7000 when slate was milled. It was proved that in milling low-grade quartz there is great economy in large rock-breaker capacity.

The inventor claimed that each 15- by 9-in. machine would break at least 50 cu. yards of stone per day, doing the work of 100 men, and that the saving of cost per yard was at least $1, or $50 per day. But these figures are below, rather than above, those actually realized in crushing and in saving.

The nature of the material to be crushed or broken is an important factor. Hard, brittle rocks are broken up faster than soft, earthy rocks. The softer rocks or ores, especially if damp, do not fall through the machine as rapidly as dry rocks. They tend to pack and clog the breaker. For such materials a stream of water is sometimes fed into the machine to promote the discharge. Clean quartzose-ore is most readily broken.

Corundum, one of the hardest of minerals, yields readily to the jaws of the crusher. Emery-rock is another example. Abrasive machines or grinding-mills are speedily cut to pieces by these minerals, but in a properly-constructed breaker, without any sliding motion of the jaws, these typical abrasives are

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* E. D. Peters, Jr., "The Sudbury Ore-Deposits," *Trans.*, xviii., 282, October, 1889.

† *Trans.*, x., 97–98.

reduced, economically, with a minimum of wear of iron or steel.

Breakers at the Anna Ore-Dressing House, Pribram, Bohemia, in 1880, were made with jaw-openings 0.42 meter (16.5 in.) long and 0.25 meter (9.8 in.) wide, and gave 200 bites a minute of 4 mm. (0.16 in.) each. The material passing the three sieves went direct to jigs or in part to be recrushed. The product between 1.5 mm. and 10 mm. (*gries*) was 10 per cent. of the amount crushed.*

V. Gyratory Jaw-Crushers.

Some of the most ingenious and successful modifications of the original Blake machines are found in the machines where the reciprocating motion of the jaw is replaced, by a gyratory motion of the movable jaw, within a conical or hopper-shaped fixed jaw.

The Gates Rock- and Ore-Crusher.—One of the most prominent of these modifications is found in the Gates crusher, in which the movable jaw is in the form of a cone suspended at the top, and is caused to gyrate within the section of a cylinder constituting the fixed jaw. The space between the jaws is convergent downwards as in the original Blake form, but is annular instead of plane, and the swinging jaw in its path around the walls of the cavity is constantly approaching the fixed jaw on one side, while receding from it on the other side. The jaw is thus acting on, or breaking, the rock continuously, without the intermittent action in the machines having an oscillating jaw. This construction gives a large product, especially with the softer rocks, such as limestone and ballasting material for railways.

Machines of this type may be called *gyratory jaw-crushers*.

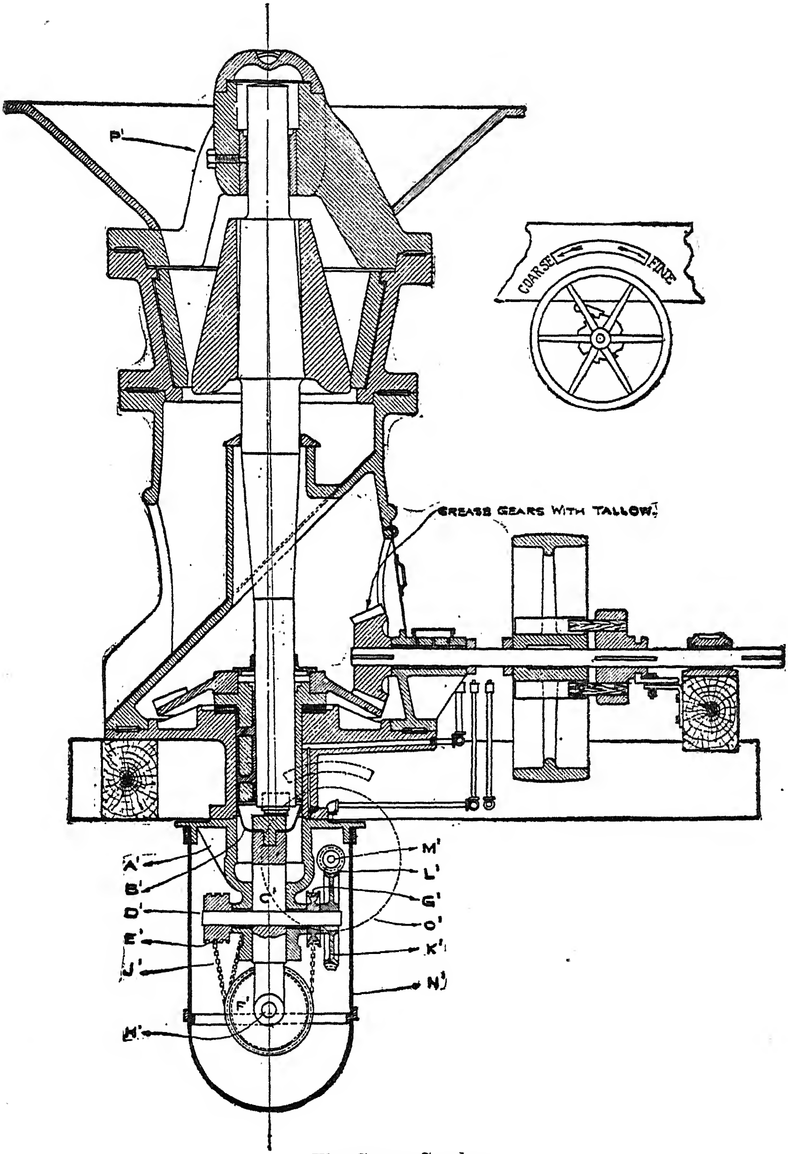
The Comet Crusher.—This type of crusher is illustrated by the accompanying section of the patent adjustable Comet crusher, Fig. 14, as manufactured by the Allis-Chalmers Co., Chicago, and patented in 1895.

VI. Some Unusual Forms of the Breaker.

The evident value of this invention and the gradually growing demand for machines, soon after its introduction,

* Clark, *Trans.*, ix., 427.

Fig. 14.



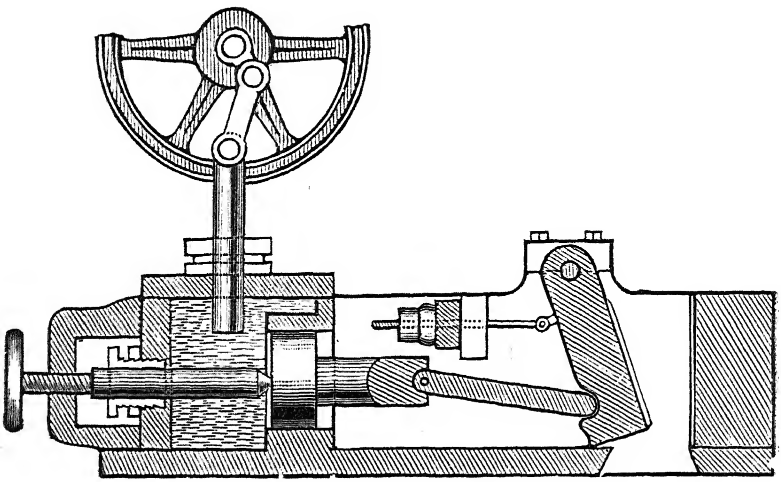
The Comet Crusher.

A′. Main adjustment-casting; B′. Oil-cup; C′. Adjusting-ram; D′. Drum-shaft; E′. Chain-drum; F′. Bottom chain-sheaves; G′. Chain guide-sheave; H′. Bottom sheave-pin; J′. Adjusting-chain; K′. Worm-wheel; L′. Worm; M′. Worm-shaft; N′. Housing; O′. Hand-wheel; P′. Supporting screw for oscillating box.

stimulated inventors and manufacturers to devise some form or modification by which the claims of the patent could be evaded. In consequence, many curious modifications of the machine were designed and put upon the market.

No crushing-machine on the Blake principle existed before the year 1858, but after the invention and before 1896 more than 100 forms or modifications of the Blake had been proposed and offered for sale, and of these more than 70 had been patented. There were more than 50 such machines before 1872.

FIG. 15.



The Smith Hydraulic Crusher.

Even after the expiration of the term of the patent and of its extension, when there were no longer any restrictions upon the manufacture of the Blake machine, generally each manufacturer proposed and made machines embodying some slight change of form or dimension, which, while having the essential principle of the invention, permitted them to claim some real or fancied improvement.

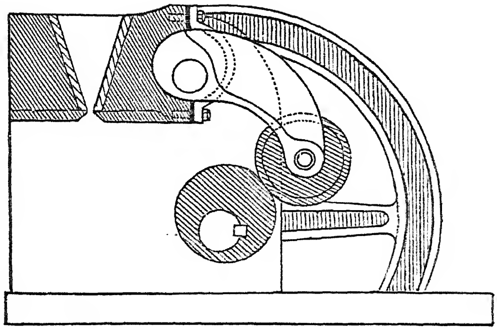
The Smith Hydraulic Pattern.—One of the earliest of these designs was a crude contrivance substituting hydraulic pressure for the toggle-joint, as shown by Fig. 15.

Three other forms planned to avoid the use of the toggle-joint are shown in Figs. 16, 17 and 18.

The Forster Crusher.—In this modification, as manufactured

by the Allis-Chalmers Co., the movable jaw is at the short end of a horizontal lever, pivoted upon a vertical bearing near the fixed jaw, as shown in Fig. 19. The long end of the lever is connected with the eccentric bearing on the fly-wheel shaft,

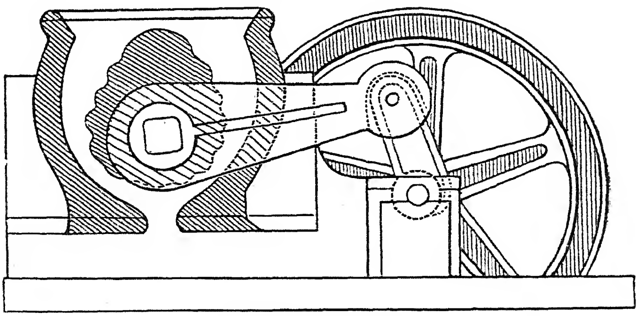
FIG. 16.



The Stafford Crusher.

and receives a reciprocating motion in a horizontal plane or arc. The space between the jaws converges downward, and the breaking is largely by the rolling, shearing action of the oscillating jaw, rather than by a direct blow.

FIG. 17.

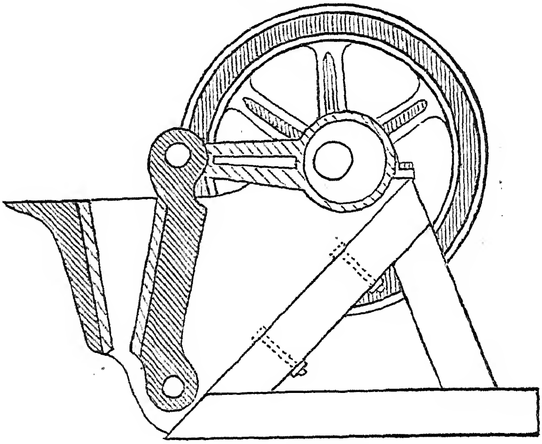


The Gates Crusher.

The Dodge Pattern.—Some inventors claimed to have made a great improvement by pivoting the movable jaw at the bottom, rather than at the top, not knowing, or forgetting, that Blake had early constructed a machine with the lower end of the movable jaw resting upon the bottom of the frame, and

that this form was discarded in favor of the arrangement of jaws to give the greatest amplitude of oscillation at the bottom of the opening, by which the delivery of broken stone or ore was facilitated and a larger product secured.

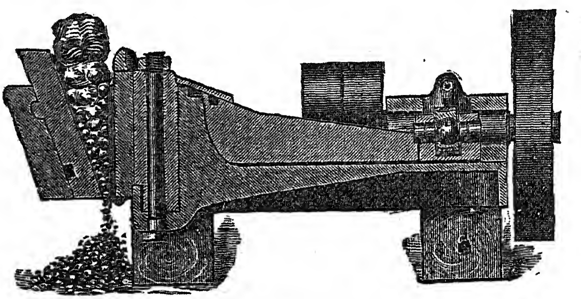
FIG. 18.



The Rawson Crusher.

The Dodge form, shown in section, Fig. 20, when the jaw-plates are new and closely set, will crush to small fragments, and holds the broken stone in the hopper-like space between

FIG. 19.



The Forster Crusher.

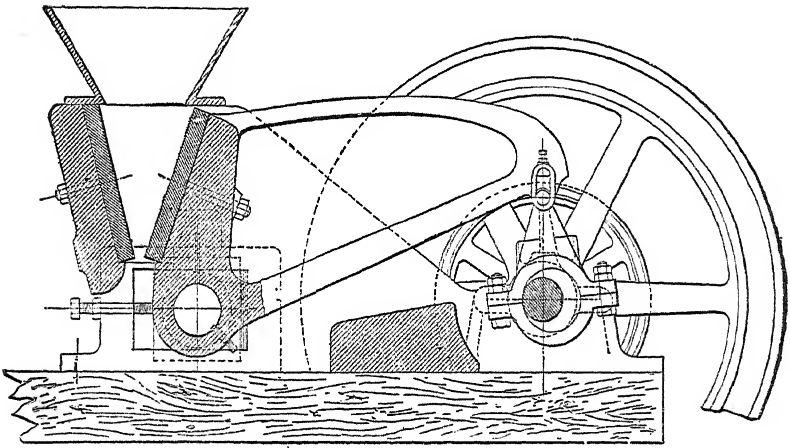
the jaws until all the fragments are small enough to pass through the narrow slit at the bottom. This fine crushing is one of the advantages claimed for this machine by the manufacturers, the Allis-Chalmers Co.

In like manner, S. R. Krom* claims as an improvement hanging the movable jaw on an axis below the crushing-faces instead of at the top, assigning as one reason for this that "the principle is correct since the strain on the jaw is greater at the bottom than at the top, and the motion should be least where the strain is greatest."

Many other machines with modifications, more curious than valuable, of the original and standard forms of the breaker, have either wholly disappeared or are now seldom seen.

The Duplex Breaker.—One of these machines designed by Gimson in England in 1878, and called the "Duplex," is shown in Fig. 21.

FIG. 20.



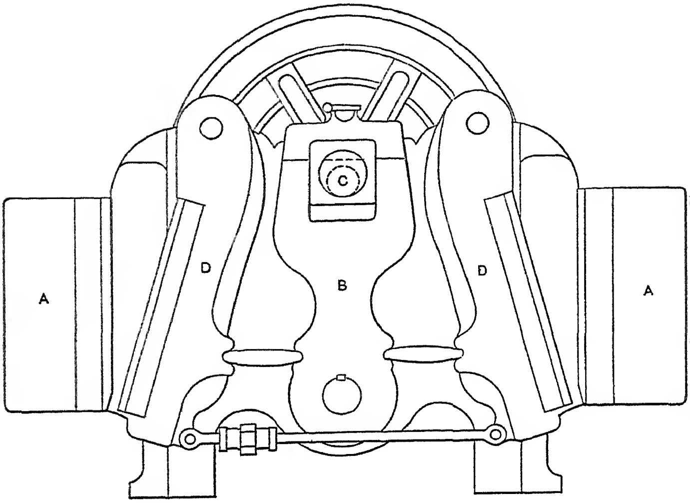
The Dodge Pattern.

It had two oscillating jaws D D, one at each end of the frame A A, with the pitman B in the center, actuated by the shaft and eccentric C.

Booth's Modification of the Wedge-Block.—In a form of eccentric-pattern Blake rock-breaker, known as the Booth (1895), the toggle-block and wedge at the end of the frame are dispensed with, being replaced by a wedge-adjustment in the center of the lower end of the pitman. Raising or lowering this wedge increases or diminishes the distance between the toggle-bearings, and thus adjusts the size of the discharge-opening between the jaws. This construction and other de-

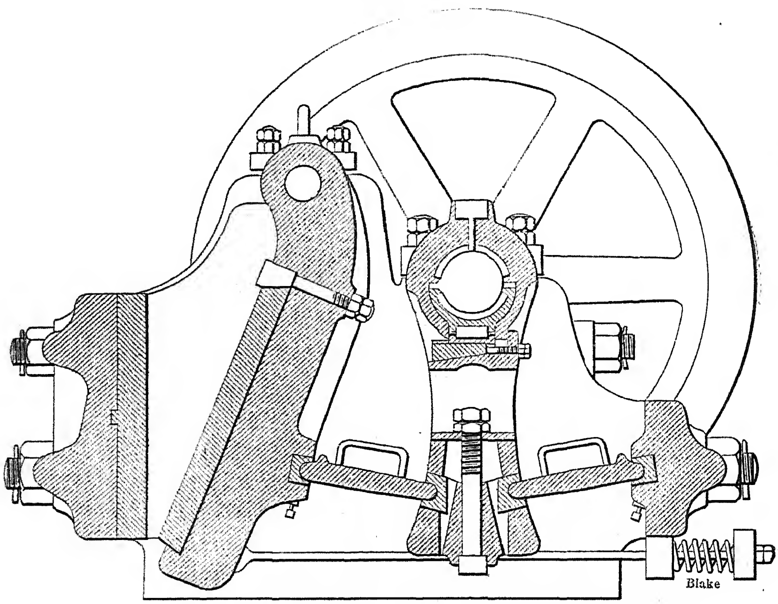
* *Trans.*, xiv., 497.

Fig. 21.



The Duplex Breaker.

Fig. 22.



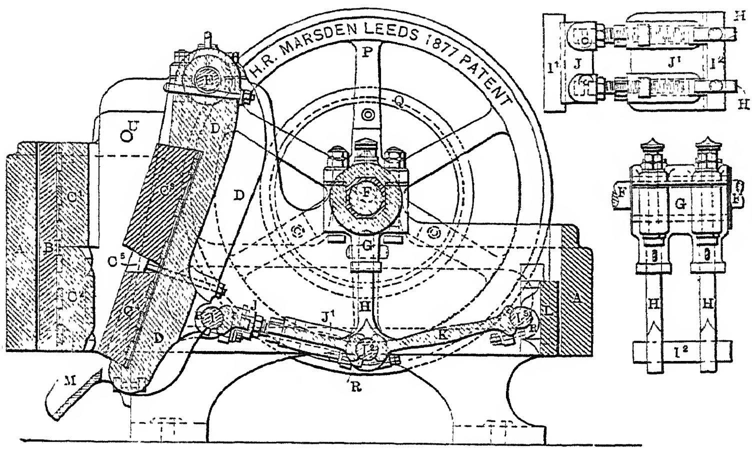
Booth's Modification of the Wedge-Block.

tails are shown in the longitudinal section (Fig. 22) of the machine as made at the Risdon Iron-Works, San Francisco, Cal., in 1898.

Marsden's Eccentric Pattern.—Fig. 23 gives a sectional view of the eccentric pattern as made by Mr. Marsden in England in 1878. The chief modifications of the standard pattern are: 1. Arrangment for lengthening or shortening the toggles by a screw-adjustment, dispensing with the wedge; 2. greater depth of frame, and duplication of reversible jaw-faces one below the other, C^1, C^2, C^3 and C^4.

In a machine by Marsden, of later construction, described by Davies,* there is a partial reversion to the early lever-pattern, for a lever is introduced and made to replace the vertical piece, being pivoted in the center of the frame in such a way as to operate the toggles.

FIG. 23.



Marsden's Eccentric Pattern.

The fixed jaw is also made in three separate but similar portions.

The Lancaster Machine.—This machine, introduced in 1889, and now extinct, is a good example of the evolution of complexity from simplicity. In the longitudinal section, Fig. 24, it will be seen that the oscillating jaw D received a downward, as well as a forward and backward, movement, communicated by the lever I, actuated by the cam R, acting upon the roller O. This construction is remarkable for the number of its wearing-parts and its greatly increased friction, as compared with the simpler forms of breaker.

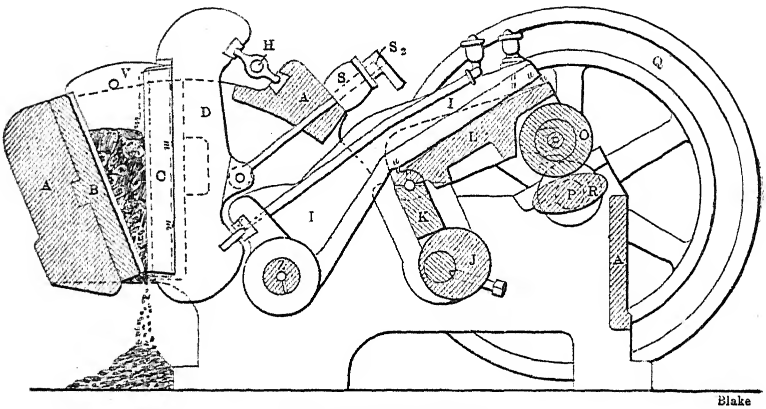
* *Machinery for Metalliferous Mines*, 1894, p. 210.

VII. Combined Crushing and Grinding Impracticable.

The two distinct operations of breaking rock and ore into fragments, and crushing to powder, are incompatible; and their combination in one machine should not be attempted.

Although the Blake breaker is now very generally known (amongst miners especially) as the "*Blake crusher*," it was devised for the special purpose of breaking stone into fragments suitable for road-metal, and not for crushing rock or ore to powder, and was named and patented as a *stone-breaker*. This name was always preferred by the inventor, on the ground

Fig. 24.



The Lancaster Crusher.

that the distinguishing feature of the machine was that of *breaking* stone into fragments instead of *crushing* it to powder. All grinding or rubbing motion was purposely avoided in the device. Blake always maintained that the two purposes of breaking and grinding could not be advantageously combined in the same machine, and that a machine which attempted to do both would not do either well. This has been confirmed by experience. Most of the rival machines, especially those made for breaking ores, were constructed to do both breaking and grinding at one operation, a superiority over the Blake breaker being claimed for the machines on this account; but all such machines have proved failures, and the combination of the direct pressure of the jaws with a grinding movement has

been generally abandoned. Any sliding, rubbing action of the jaws results in ruinous wear and loss of iron. And as it requires more time to reduce a given bulk of rock to fine powder than to break it into fragments, a breaker with a grinding attachment cannot be fed to its full capacity. It will bite and break faster than it can grind.

In a machine intended for a definite purpose, Mr. Blake was never content to impair the best result in its use for that purpose by trying to effect something else with the same machine. For this reason he always steadily refused to cater to the demands of mining agents, that he should make a machine which would grind as well as break; and he thus lost many orders which went to less scrupulous makers of modifications of his invention.

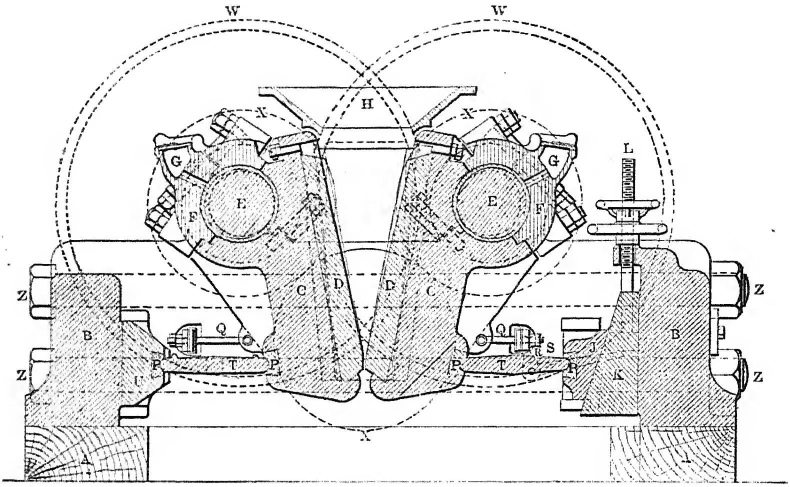
There has always been a great demand for a single machine combining the functions of a breaker and a grinder; and inventors and manufacturers have produced a variety of such machines to meet this popular demand. These constructions form a class by themselves, and may be designated as hybrid machines.

The Hanscomb Machine.—One of the earliest and least durable of this class was designed by Hanscomb, and constructed at the Miner's Foundry in San Francisco, about 1863. Its jaws, instead of being upright and convergent, were inclined. The wide convergent space between them at the top was extended downwards between, approximately, parallel surfaces for a considerable distance. An oscillating sliding-movement given to the upper jaw was intended not only to crush the larger masses above, but also to grind the fragments into powder below. Two other examples of this class of machines are presented.

Howland's Crusher and Pulverizer.—One of the most remarkable of these hybrids is the machine designed by Howland, in which two oscillating jaws are mounted in one frame in opposition, and occupy practically the place of the pitman in the Blake eccentric pattern. Fig. 25 shows, in vertical section, the construction of this machine.

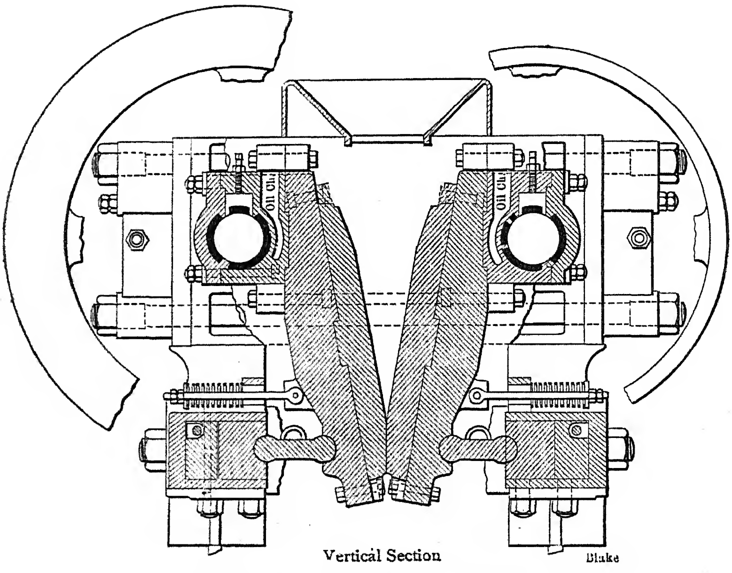
There are two independent driving-shafts E E, each with its eccentric passing through the top of each jaw, by which these jaws are made to approach each other, while having at the same time an upward and downward motion between the toggles T T.

Fig. 25.



Howland's Crusher and Pulverizer.

Fig. 26.



The Oliver Crusher and Pulverizer.

The Oliver Crusher and Pulverizer.—A machine of similar design and construction was proposed and advertised at Chicago in 1896, by T. T. Oliver.* It was known also as the "Differential Crusher and Pulverizer." Fig. 26 represents this machine in vertical section.

VIII. The Chief Uses of the Stone-Breaker.

This invention has two great fields of application, involving, respectively, constructive and destructive work.

Under construction, we may place the production of broken stone for concrete foundations and superstructure; for submarine work; for bridges, etc.; roadways and paths, and for ballasting railways.

Under destruction, or disintegration, we place its various applications to mining and metallurgy, the breaking up, crushing and disintegration of hard vein-stones, to loosen and liberate the valuable portions for the purpose of their separation from the worthless gangue.

Concrete Constructions.

In modern constructions, engineers and architects make large and increasing use of broken stone. It is employed in the form of béton, or concrete, not alone in foundations, but in superstructures. Its use on a large scale has of late been specially evident along the route of the subway under construction in the avenues and streets of the city of New York. Many thousands of tons of clean, broken stone have been required for that work. Much of this stone is brought from quarries at Weehawken and at different points along the Hudson river. A thousand men working in the old way with hammers would scarcely be able to supply the daily demand, and, moreover, if such a supply were offered, the cost of the hand-broken stone would prevent its use.† But the breaker not only renders the use of broken stone economically practicable, but secures a better quality of concrete than can be had from hand-broken rock.

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* See *American Miner and Engineer.*

† This is an instructive, though by no means isolated, illustration, of the principle that machinery, in the long run, and often even in its immediate effect, does not deprive manual labor of occupation. In this case, if machinery did not supply the demand, *there would be no demand.*

The rock-breaker has thus made forms and methods of construction possible which, before its introduction, were not even considered as conceivable alternatives by practical engineers.

Macadam Roads.

In the breaking of stone for roads built upon the Macadam plan,* the stone-breaker finds one of its most important and extended spheres of usefulness. Without a mechanical stone-breaker the general construction of Macadam roads would be impracticable. The economy of building with broken stone requires a large and constant daily supply, greater than could possibly be had by hand-work, unless an army of men could be employed and find room to work. The constant supply is one of the main elements of economy in the work. It is not so much the initial cost of breaking the stone, as the teaming, rolling and other details of road-making which are affected by the regularity of the supply. The Massachusetts Highway Commission found it necessary, in order to keep all the departments steadily at work without loss of time, to have a breaker with a capacity of at least 100 tons of stone a day.† This quantity is easily secured by using a 15- by 9-in. breaker, which will break from 50 to 60 cu. yards per day,—an amount which would require the diligent labor of 100 men.

Size of Broken Stone for Road-Metal.—For macadamizing, evenly-broken stones, nearly uniform in size (about 1-in. cube), are most desirable. This uniformity is best secured by the stone-breaker. Although the requirement as to size is now generally that the broken stones must pass a 2-in. ring, Macadam laid down the rule that "a stone which exceeds an inch in any of its dimensions is mischievous," basing this dictum on the fact, observed by him, that a cart- or wagon-wheel in

* John Loudon Macadam, born at Ayr, Scotland, September 21, 1756, went to New York in 1770 to reside with an uncle, a loyalist, and, according to his own account, returned to Scotland in 1783, when the Scotch Turnpike Acts had been about twenty years in operation and roads were still under construction everywhere. He secured an appointment as Commissioner of Roads, and afterwards removed to Bristol, where he obtained a similar post and was made a magistrate. Having a positive mania for road-making, he began, about 1794, to travel at his own cost over the country, from Inverness to Land's End, searching for a well-made road and the best means of making one. (*Condensed, in part, from an article on Macadam's plan of road-making in the St. James Gazette,* 1883.)

† *Report*, p. 39.

passing over a stone, which presents a surface longer than 1 in., tends to lift one or the other end out of its bed. In practice he found it best to fix upon a weight of 6 oz. for each fragment, and his surveyors carried scales to test the weight of the larger stones in a heap.*

The Massachusetts Highway Commission in its contracts for broken stone for Macadam roads requires three sizes to be used for the covering of the road-bed: first, a layer of broken stone not larger than 2.5 in., or smaller than 1.25 in., in largest diameter; secondly, a layer, 2 in. deep, of broken stone not larger than 1.25 in., or smaller than 0.5 in., in largest diameter; and, thirdly, on the top of this second layer, screenings that will pass through a 0.5-in. mesh, to be watered and rolled until the mud shall flush to the surface. Care is taken to lay on just enough of the screenings to cover the large stones.†

Cost of Breaking Stone or Ore.—The cost of breaking by hand for road-metal before the invention of the breaker was from $2 to $2.50 per cu. yard, and pieces smaller than 2 in. in diameter made up less than 5 per cent. of the whole mass. This small quantity did not justify any attempt to screen out or separate the fine from the coarse. Such fines are needed for top-dressing on Macadam roads, and are readily secured from machine-broken rock by ordinary screening. But formerly, after covering a road with Macadam road-metal of the standard size, it was left to the pulverizing action of vehicles and horses to secure in time an approximately even surface by wearing down. Such roads were not only disagreeable and unsatisfactory, but were costly to build and to maintain.

The rock-breaker has not only reduced the cost of breaking to less than 50c. a cu. yard, but breaks the stone to any required size, and produces a sufficient quantity of fines to make a complete top-dressing for the road and a smooth, hard surface, far superior to any which can be obtained from hand-broken stone. The cost in day's work of breaking stone by hand for Macadam road-metal is stated, for sizes of from 1.25 to 1.5 in., of very hard rock, one day's work for every 0.6 to 0.44 cu. yard; of rock,

* It is said of the ancient Romans that their requirement as to the size of broken stone for road-making was, that each piece could be passed between the teeth of a workman.

† *Rept. Mass. Highway Commission,* 1895, p. 50.

less hard, one day's work will break from 0.7 to 0.6 cu. yard; and of soft rocks, from 1.76 to 1.17 cu. yards. In other words, one laborer can break in a day from 0.44 to 0.60 cu. yard, if the rock is hard; if soft, from 0.6 to 0.7 cu. yard; and if very soft, from 1.17 to 1.76 cu. yards.

To spread from 12 to 14 cu. yards is regarded as a day's work.*

Superiority of Machine-Broken Stone.—It is found that machine-broken stone packs and binds better than that broken by hand, and far better than any gravel. This confirms the results of experience in making concrete. The machine deals easily with the hardest rocks, which, though best suited to stand the wear of roads, are naturally avoided when breaking by hand is required.

The breaker has thus not only cheapened the production of broken stone, but at the same time assured (and on a large scale) a better product. Moreover, by its automatic delivery of the product, it permits the separation into different sizes, without handling, by passage over gratings or through screens set at the proper inclination, and the (still automatic) delivery of these sizes into separate bins.

Telford Roads.

Sizes of Broken Stone Required.—For Telford roadways the requirements of the Massachusetts Commission are, on the sub-grade, a foundation of stones from 4 to 10 in. wide, 6 to 20 in. long, and not less than 8 in. thick. The stone must be sound and hard, placed by hand vertically and lengthwise across the roadway so as to form a close, firm pavement. These stones are wedged in place by smaller ones; all projections are broken off by hammers; and then the foundation is rolled. Apparently, no top dressing of broken stone was applied to their layer of large stones.

The stone used was trap-rock and cost 40 cents per ton at the quarry; 25 cents per ton for teaming, and 33 cents per sq. yard on the road, all laid. This was the cost on the Westfield road, in 1894.

* *Treatise on the Science of Road-Making*, by Clemens Herschel, C.E., Boston, 1870, p. 31.

Macadam vs. Telford Construction.—One result of the use of machine-broken stone has been the practical settlement of the old controversy respecting the comparative merits of the Macadam and Telford systems of construction, which agitated road-building engineers a hundred years ago. It is no longer necessary to economize in the quantity of broken stone by putting down a substratum of blocks of stone, but the entire depth of the construction may be made of machine-broken stone, graded from the coarsest at bottom to the fine on the top; or the whole may be of stone broken to the uniform size of about 1 in., thus realizing the ideal form of road-construction insisted on by Macadam, who condemned the use of larger stones at the bottom than on top, because of their tendency to work upwards towards the surface.

IX. General Deductions as to Road-Making.

The machine has not only cheapened and increased the production of road-metal, but has made it possible to build a better road in much less time than formerly. It has improved the art of road-building, and made it possible in one operation almost to complete and perfect the road-surface, making it ready for immediate traffic.

It is to these improvements in road-construction, hardly less than in the reduction of cost, that the country owes the great improvements in its roads, and the general demand for, and appreciation of, good roads which the last 25 years have developed.

Roads for Automobiles.—The construction of good roads with a hard, smooth top-dressing of fine stone has had a great influence upon the use of bicycles, and more recently of automobiles. It is not only possible, but probable, that in the near future special roads will be constructed for the use of automobiles. It is certain that even now, while the limited construction of good Macadam roads has made the use of automobiles possible near the great cities, the automobile interests are being exerted in favor of a more extended and universal system of such roads. The project of an automobile road between New York and Chicago, or at least the completion of a good Macadam road between these two great cities is a case in point.*

* The inspection of a proposed route for a highway from New York to Chicago was begun by a party in a steam road-wagon in September, 1902; and it was re-

It is an interesting fact that, as early as 1872, the late Frederick Law Olmsted predicted that one result of the invention of the Blake stone-breaker would be the coming of steam road-locomotives into practical use, thus foretelling the advent of the automobile as a consequence of the Blake invention.

X. The Broken-Stone Industry.

Stone-breaking by machinery has become a new industry, producing a staple of trade, manufactured without regard to its immediate use, and kept for sale to contractors and builders, makers of private roads or walks, and purchasers representing other purposes.

Abundance of Trap-Rock.—Fortunately, there is in New England, and throughout the country generally, an abundance of material suitable for road-building.

The long line of hills of trap-rock, extending from Mount Tom on the north, through central Massachusetts and Connecticut to Long Island Sound on the south, gives an inexhaustible supply of the very best material for Macadam road-metal, railway-ballasting, or concrete. Crushing-plants have been established at various points, especially near Westfield, Mass., and at Meriden, Conn. Many of the towns in these States have their own machines, which supply broken stone for the construction and repair of the town-roads. The city of New Haven has such a plant at Pine Rock, near West Rock. One firm, John S. Lane & Son, of Meriden and Springfield, has quarries at Meriden on the New York, New Haven and Hartford R. R., at Westfield, on the Northampton road, and on the North river at Weehawken, New Jersey. The capacity of its crushers is 2,500 tons daily, and its production of broken stone is about 400,000 tons annually.

Massachusetts Highways.—The Massachusetts Highway Commission was using in 1892 between 125,000 and 160,000 tons of broken stone a year in the building of State roads. The different cities and towns of that Commonwealth were proba-

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ported that of the 850 miles of road between New York and Chicago 320 miles are already in first-class condition. New York is taking a modern interest in the good-roads project, and upward of $500,000 has been expended within a short time on the roads of the State. (*Condensed from an article in the N. Y. Tribune, Sept.*, 1902.)

bly using as much more; so that it is safe to say that from 300,000 to 400,000 tons are broken every year in Massachusetts to be used in the building of roads.

There are seven large crushing-plants in Massachusetts, located along the different railroads, from which broken stone of the best quality is distributed to all parts of the State reached by railroads. In addition, there are about 150 rock-breakers used by the different municipalities and contractors.

Under the direction of the Massachusetts Highway Commission, and at the expense of the Commonwealth, there have been built in the last 8 years about 425 miles of broken-stone road, and during the same period the towns of the State have built about 500 miles more.

"In 1894, the first year of the existence of the commission, the State appropriated $300,000 for roads; in 1895, $400,000; in 1896, $600,000; in 1897, $800-000. In 1898, on account of the war, the appropriation was cut down to $400-000. In 1899 it was $500,000, and in 1900 the same amount, making in all $3,500-000 spent on the State roads."*

In New Jersey the total number of miles built under the State-Aid Act, up to the year 1901, was about 700, at a cost of $3,244,000.

Railway-Ballast, Concrete, etc.—The increasing demand for broken stone for construction, road-making and railway-ballast has attracted the attention of the United States Geological Survey. Its latest report on *Mineral Resources* says, that the total value of crushed granite in 1901 was $3,003,443; in 1900, $2,571,899,—a gain of $431,544. The value of railway-ballast was $516,768, of road-metal (Macadam, etc.), $2,008,966, and of concrete, $447,709. The greatest value for railway-ballast was produced in Delaware; for concrete, in California; and for road-making, in New Jersey. North Carolina came second, California third, and Pennsylvania fourth, in the value of railroad-ballast; Pennsylvania second, and New York third, in value of road-making material; and Massachusetts second, and Maryland third, in the value of concrete.†

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* Charles M. Ross, "Proc. International Good Roads Congress," *Bull. of Public Road Inquiries*, No. 21, U. S. Dept. Agriculture, 1901, p. 35.

† "The Stone Industry," 1901, *U. S. Geol. Survey*, 1902.

XI. Use of the Stone-Breaker in the Mining Industry.

The second great field of usefulness of the breaker is found in connection with mining and metallurgy, in the mechanical disintegration of ores for the separation of their valuable portions from the worthless rock or gangue. In this field, perhaps, it is most widely employed as an adjunct to stamps in breaking up gold-bearing quartz, or associated with other machines for fine crushing and grinding. Some of those persons who witnessed the experimental trials made by the inventor with his first stone-breaker, and noted the ease and rapidity with which the hardest boulders of trap-rock or of quartz were reduced to fragments, recognized at once the importance of the machine to the mining industry; and arrangements were concluded for the introduction of the invention at the mines on the Pacific Coast.*

The utility and importance of this invention in the mechanical treatment of ores and minerals is now so well known to mining engineers that it is difficult to understand why some years of effort, beginning so late as 1861, were required to overcome the well-grounded prejudice against any new machine for crushing ores. But the explanation is simple. For many years the owners of gold-producing mills in the Appalachians and in California had been pressed by inventors and manufacturers to buy some new form of crusher or grinder, like huge coffee-mills, large iron balls rolling in troughs, or other devices for breaking and pulverizing ore; and, trying such machines, had found all of them to be costly, ineffective and short-lived, and had sent them to the scrap-heap. It is, therefore, not strange that representations regarding an entirely new form of rock-breaker were received with incredulity and distrust.

The breaker is used not only to prepare ore for stamps, but also to reduce ores to sizes suitable to be fed to rolls or to arrastras. The product of a breaker set closely is often sufficiently small to be passed directly to jigs. This is especially so in the case of the multiple-jaw modification.

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* The right under the patent to use and manufacture the Blake rock-breaker in the States of the Pacific Coast was given to the son of the inventor, Charles T. Blake, Edwin Tyler (both graduates of Yale, Class of 1847) and myself, associated under the firm name of Blake & Tyler, by which the business in California was carried on until the expiration of the patent.

Among the various other applications of the machine is its use in the crushing of emery-stone and corundum, the hardest of common minerals. It is used, also, to prepare hard iron-ore for the furnace and to crush limestone for flux at iron- and copper-furnaces. It renders great service in breaking up copper-matte, and in preparing ores for assay and for sampling-works by a preliminary crushing to a size permitting a good average mixture to be made.

Small jaw-breakers are found to be indispensable in all our great assaying establishments in the preparation of coarse samples for grinding or for the bucking-board.

First Application in the Mining Industry.—In the year 1861, by personal influence with General Frémont and Frederick Billings, then largely interested in the Mariposas Estate, California, and by my promise to attend personally to the installation and my giving guarantees of success, I obtained permission to set up a rock-breaker at the Benton Mills, on the Merced river, Mariposa county, California.

The mill at that time was under the charge of Silas Williams as superintendent, with Trenor W. Park as manager of the Estate, and was working 25 or 30 tons of gold-quartz a day. Twenty-five Chinamen with hammers were engaged in spalling the blocks of quartz to a size suitable for feeding to the stamp-batteries.

The breaker, made in New Haven, was sent out to San Francisco by sailing-vessel around Cape Horn, as was the practice for several years after.

When it reached the Estate it was received with great reluctance by superintendent Williams, who declared he had no faith in it; that he was tired of experiments at the expense of the Estate, and that it was his conviction that this trial, like those of other machines, would be a failure. It was only after the machine had been put into successful operation before his eyes that he became one of its most enthusiastic admirers.

When the first block of quartz was dropped between the jaws and disappeared below in a heap of fragments, the Chinamen crowded around in amazement, and, realizing that their occupation had gone, threw their hammers away. Two or three hours' work with this machine broke up a full supply for the mill, and did the work better than the Chinamen had done it with their hammers, at a cost of $25 a day.

After this first practical demonstration of the utility of the crusher at a gold-mill, the invention was soon in demand for the gold- and silver-mills upon the Comstock Lode in Nevada (then in *bonanza*), and at other mines, until, to-day, there is scarcely a quartz-mill of prominence in the United States or abroad that is without a rock-breaker in some form. Breakers are a standard article of manufacture by all the great works engaged in the production of mining-machinery.

The Homestake mine in the Black Hills, South Dakota, gives a good example of low-grade gold ore-crushing on a large scale. In the nine stamp-mills of this company 3,000 tons of ore are crushed daily. Such a quantity of ore could not be handled without the aid of breakers, and without their aid the property, probably, could not be made to pay.

Advantages Besides Saving of Cost.—The saving of cost of breaking, as compared with hand-work, though so great and evident, is, perhaps, one of the least of the advantages of the use of the breaker. The ores are more uniformly broken by machine than by hand. This is an important element in the proper feeding of a stamp-mill. The regularity of size of the fragments permits and invites automatic feeders, by which the capacity of stamps is increased at least 15 per cent. over the results by hand-feeding. It is usual to consider that, with a breaker and automatic feeders, the capacity of a stamp-mill is increased 25 per cent. With rock-breakers, stamp-milling becomes automatic, from the dumping of the ore into the breaker.

There is another advantage in the use of breakers instead of hand-spalling, which is especially evident in the case of gold-quartz mines, where the gold occurs in masses or bunches of considerable size and value, spread through the quartz, as, for example, at some of the mines at Grass Valley, in California. When such golden masses find their way into the mouth of the rock-breaker the machine does not stop to admire and covet the metal as it drops from its crystal matrix, but remorsely passes the gold along to the self-feeder, where it finds its way to the retort and crucible instead of, possibly, to the cabinet-shelves of some enthusiastic collector, or into the pocket of a human rock-breaker.

There is still another advantage, which may not be so evident at first, but which should be appreciated in these days of

strikes,—the value of an agency which strikes only for the benefit of its employer!

XII. Industrial Value of the Invention.

The industrial value of the invention is not easily computed in dollars, if at all. At the time of the application of the inventor for a renewal of the patent, an attempt was made to show the direct saving to the industries in which the breaker had then been used. It was computed that in ten years' time, prior to 1872, the direct saving of labor expense by 509 machines was not less than $55,560,000.* The indirect savings were not estimated; but the large amount of direct saving could be clearly shown from the actual working-records of the breakers then in use. Similar careful calculations, based upon the working of a considerable number of the machines in operation since that date, give figures so large that I refrain from their presentation, although the amount is based on definite and detailed returns received, excluding partial returns and estimates.

The introduction of the breaker marks a new era not only in the manipulation of ores, but in many constructions and mechanical operations made possible by its use. We have seen that it has cheapened, improved and stimulated road-building and concrete construction; that it has cheapened and increased the production of the precious and common metals; and that it has become an indispensable adjunct of modern engineering progress.

When we consider, also, the enormous extent of the mining industry throughout the world, valued in the United States, alone, by hundreds of millions of dollars yearly, in the production of which the Blake rock-breaker has been an effective agent, we cannot withhold our unqualified recognition of its claim to a prominent place among the greatest labor-saving inventions and civilizing agents that were produced in the nineteenth century.

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* Digest of evidence before the Commissioner of Patents.

DISCUSSIONS.

The Evolution of Mine-Surveying Instruments.

Further Discussion of the Paper of Dunbar D. Scott (Buffalo Meeting, October, 1898). See *Trans.*, xxviii., 679; xxix., 931; xxx., 783, 803; xxxi., 25, 716, 884 and 921.

E. A. H. Tays, San José de Gracia, Sinaloa, Mexico (communication to the Secretary): In Mr. Scott's admirable paper* is described the old method of mine-surveying called Rössler's, and the illustration on page 686† shows the manner of working. The instruments used are those called the gimbal-compass and the clinometer.

On page 686 it is stated that this method is in vogue in some European mines even to-day. I doubt if many members of the Institute have ever seen such instruments, and it will be news to a number of them that they are manufactured to-day by the Keuffel & Esser Co., New York City.

In my judgment, this set of instruments, though crude and antiquated, should be included in the surveying-apparatus of every mine large enough to require an engineer. I have always heard the compass called the binnacle compass, after the nautical instrument on the lines of which it is constructed.

The first I ever saw was in the outfit of a Mexican mining company of which I was engineer. I looked it over, but was too conservative at that time to give it a trial; and it was not until the next year that I really learned its value and began to use it. The Mexican company sold out, and an American company fell heir to the instruments. I met the American engineer of the new company just before he took his place. In going over the instruments he picked up the compass and clinometer case, remarking: "Say, Tays, do you know this is a bully instrument?" and gave me a description of its merits. After a number of years of experience, I fully concur that it is a "bully" instrument, and recommend its use to the profession at large.

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* *Trans.*, xxviii., 679.

† Or, special volume on "Mine-Surveying Instruments," p. 8.

I do not wish to be understood as advocating its substitution for all other mine-instruments, but as a handy, labor-saving device, it is extremely useful. There is no need of the elaborate contrivance shown in Fig. 7.* Hook-pins or nails can be driven into a stull or cap, and the cord stretched tightly between the two points. The clinometer-reading, for the vertical angle, should be made at each end of the line and the mean taken, which gives very accurate results. The compass should be tested frequently with the transit, as the circle is liable to get knocked to one side or the other of the line of the arms; and, since the resulting error might amount to several degrees, this is to be guarded against. In taking the bearing, the string can be left hanging loose; and this is at times very convenient, as when the two points are set in the roof of a drift, etc. The instrument is extremely useful in the survey of unhandy stopes, winzes and upraises, where it would be extremely difficult to work with a transit; also for locating monthly the lines of stopes, especially in faulted and irregular ore-bodies; and in making the unimportant but (with the transit) bothersome minor connections and communications, which are necessary each month, in every mine of considerable size. With ordinary care, it is a very valuable aid to the engineer in his daily work inside the mine.

I once surveyed the workings of an old Mexican mine, of which two were accessible to the transit, doing the remainder with the binnacle compass and clinometer. The transit-points were very accurately connected with a thorough surface-survey covering several mines in the vicinity. Two years later I ran a connection for ventilation between an irregular drift, more than 1800 ft. long, from one of the adjacent mines, and a point in the old workings referred to, missing the point by only half the width of the drift, and checking in altitude within less than 3 ft. Of course the longer workings were located with the transit, as workings of any importance always should be.

As a valuable auxiliary to the engineer's outfit the binnacle compass with clinometer is to be recommended; and, as now manufactured, it is packed in a neat semicircular case with straps, and costs $50.

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* On the page cited above.

BENNETT H. BROUGH, London, England (communication to the Secretary): There still appears to be a certain amount of confusion regarding the invention of the micrometer eye-piece and of the stadiametric principle. The facts are, I think, as follows:

A micrometer with a fixed *virgula* was employed by Huygens, as stated in his book printed in 1659, to measure the diameter of the planets. In 1662 the Marquis Cornelio Malvasia used silver cross-wires, fixed in a frame, by means of which the apparent diameter of planets was estimated. In December, 1666, the French astronomer Auzout communicated to the Royal Society of London an account of his invention of a micrometer with a movable silk thread or hair. In March, 1667, it was pointed out by Richard Townley, of Lancashire, that the idea of measuring small angles by means of the revolutions of a micrometer-screw in combination with fixed and movable wires, applied by Auzout and Picard, had been anticipated in 1639 by the young Englishman, Gascoigne, who died at the age of twenty-three at the battle of Marston Moor. Gascoigne's correspondence was not published until long after his death. Neither of these inventors contemplated the direct measurement of distances on the earth by means of the visual angle. Geminiano Montanari, in 1674, effected this by the use of from 12 to 15 parallel equidistant hairs or wires, in conjunction with a vertical staff of fixed length.*

This differs but little in principle from the later method, in which the length of the staff varied, while that of the image remained constant. Of the latter type was the instrument contrived by James Watt in 1771. According to the account left by him, the telescope had, in the focus of the eye-glass, two horizontal hairs, about one-tenth of an inch apart, and one perpendicular hair, and the rod was of the target type, the divisions being marked with the number of chains represented. William Green's invention in 1778 was exactly similar; but he used a telescope of higher magnifying power, and could consequently measure greater distances.

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* *La Livella Diottrica,* Bologna, 1680.

Silver-Mining and Smelting in Mongolia.

Discussion of the Paper of Mr. Y. T. Woo, p. 755.

BY BENJAMIN SMITH LYMAN, PHILADELPHIA, PA.

Mr. Woo's succinct description of the mining and smelting of silver-lead in Mongolia, with the roasting-and-reduction process and cupellation, has much interest as a picture of methods that not only may have been in use, as he suggests, a thousand years ago, long before the existence of mining schools or chemical laboratories, but probably vary little, if at all, from the practice of prehistoric times, when King Priam's handsome silver vases, cups and bowls were formed. For it is highly improbable that such large objects were made from comparatively rare native silver, and the metal must have been smelted from ore, and most likely in great part from galena, with cupellation of the lead.

Dr. W. A. P. Martin, in his excellent book on the *Lore of Cathay*, points out that Chinese alchemy is over 2000 years old, antedating the European by at least six centuries; and he infers that the Chinese skill in metallurgy and many branches of practical chemistry owes its origin to "those early devotees of the experimental philosophy who passed their lives among the fumes of the alembic." Those alchemists, however, may have more likely derived some of their leading ideas from the mysterious, and at that time wholly unexplainable results observed in already very ancient metallurgical processes; in which, for example, certain stones were transmuted, as it were, into metals widely divergent in character from their ores, and even silver and gold were obtained from the most unlikely-looking materials. It is therefore, in any case, not improbable that the Chinese may have preceded western nations in the discovery of metallurgical methods.

At all events, it is now evident that the Japanese acquired these arts from China, the former source of all their higher civilization. My own observation of old-fashioned silver-smelting at Hosokura, on the main island of Japan, and about 220

miles northerly from Tokio, agrees so well with Mr. Woo's in Mongolia, as to show the common origin of the methods, and that they have not probably changed in any important particular since the first opening of the Hosokura mines about 1100 years ago. The precipitation-process was used there, and was briefly noticed in my *Report on the Second Year* [1877] *of the Survey of the Oil Lands of Japan*, published at Tokio in 1878, page 43; as follows:

"The galena is smelted in a small furnace or hearth (now only one), about a foot and a quarter in diameter, with the addition of iron in the form of old coins. The charge is [in our pounds]: 83⅓ lb. of ore and the third (last) cake of slag of the preceding operation; 23⅓ lb. of iron coins, or 19⅙ lb. of new iron; 58⅓ lb. of charcoal (costing about one cent a lb.). The operation lasts two hours, and there are three operations in the morning; in the afternoon, the hearth is repaired. The product is about 50 lb. of lead to each operation, or 150 lb. a day. The lead (except the poorer part) is cupelled by two women on a hearth of common wood-ashes, and the litharge is afterwards reduced again to lead; with a loss of 25 to 30 per cent. of lead in the whole process. As already seen, the monthly product of silver (1¼ lb. avoirdupois) is about one-half a tenth of one per cent. of all the lead. . . . . The smelting operations are extremely interesting as agreeing closely in many respects with the processes of western countries, though they have apparently been handed down for many generations, and are the result of innumerable experiments made without any knowledge of the chemistry involved."

It now appears probable from the close agreement with the Mongolian methods that they must be the result of very ancient experimenting; so that they were introduced into Japan as an already established practice 1100 years, or more, ago. Pumpelly* observed at Yurap in Yesso lead-smelting by a method closely similar to that of Hosokura, with a furnace-charge of like character and amount; but with a chimney above the furnace. The bellows used there and at Hosokura is like that of Mongolia.

The work in the Hosokura mines in 1877 was merely glean-

* *Geological Researches in China, Mongolia and Japan*, 1866, p. 81.

ing from former rich workings that had reached to 120 and 128 feet below natural drainage, and that had been finally abandoned in 1872. In one mine, the water was raised 120 feet with wooden pumps in three lifts by 540 men working in three eight-hour shifts of 180 each. Pumpelly (p. 17) describes mine-bailing in the Chinese province of Chihli, just like the Mongolian; but says that the men bailing were blind men, a characteristically practical idea in that country.

The open cupel-bottom at Hosokura was much smaller than Mr. Woo's Mongolian one, and was only a foot in diameter, but two of them were used for the 150 pounds of lead produced the preceding day. The ashes were smoothed into a gentle hollow with a paper bag full of ashes flattened into a lenticular shape, with the ends of the paper gathered into a sort of handle on the upper side. At the last touch, the very middle of the bottom was slightly pressed with the smoother. Over the cake of lead on the bottom, charcoal in pieces 8 or 12 inches long and 3 inches in diameter were set up in truncated-cone fashion, and kindled by some live coals inside. At the end of about three hours, the fire was removed, and the lead sprinkled with water and cooled and separated from the litharge. One bottom was then re-formed, and all the now remaining lead placed upon it; and treated in the same way for another three hours, and then cooled off as before. Then a smaller bottom, hardly nine inches across, was formed; but with a depression in the middle, a quarter of an inch deep and an inch and a quarter across; and, under like treatment again, the brightening came in about two hours. The woman in charge quickly cooled the silver by blowing on it through a small bamboo tube; removed the cake of litharge with the silver still red below, and poured on water. The silver button weighed about an ounce and a sixth, Troy. The second melting, it was said, made less litharge than usual, and consequently the third, more, in a longer time than usual: "because the ashes were bad." They are from any kind of wood, and are bought by weight from the country people, who are apt to mix loam and sand with them to increase the weight.

Mr. Woo's straightforward, clear paper is an earnest of much light that may be expected before long to be thrown upon many obscure oriental and archæological matters by

Chinese trained in western science and, at the same time, otherwise well fitted and conveniently situated for such fascinating investigations.

Mr. Woo: I have nothing to add to this discussion at present, except the fact (which may interest those who will deal in mining property in Mongolia hereafter) that the royalty exacted by the Government on gold and silver will be 7 per cent. of the output. Mongolia, hitherto under the control of a military officer, will receive a civil governor instead.

Puddled Iron and Mechanical Means for Its Production.

Discussion of the Paper of Mr. Roe, p. 551.

BY JOSEPH HARTSHORNE, POTTSTOWN, PA.

Since I have had the pleasure of watching the development of this process very closely, I feel that I ought to say a few words on the subject, although I cannot add much to what Mr. Roe has already said. I wish, however, to bear witness to the hard work, persistence and skill which have been exercised during the past two years, and which have so well deserved the success attained.

Those of us who remember the history of the past efforts in this line, such as the rotary puddlers, in which also some of us had a part, can easily appreciate the problems involved, and may well be skeptical as to the outcome. Such, at least, was my frame of mind when the process first came under my notice. Now, after having seen every heat, but three, of the many made, it really seems to me that a process and plant for the mechanical puddling of iron has at last been developed which is practical, economical and successful. Of course I do not mean by this that either the process or the machines are developed to their highest point, technically or economically, but that, in my opinion, these goals are in plain view, and that the difficulties which remain are such as will be overcome by developing the skill of the operator through practice;

by making a few changes in the puddler, indicated by experience; and by giving greater freedom of escape for the slag pressed out by the squeezer. These latter changes have been begun.

Of course, it is not necessary for me to point out the many advantages which will accrue from this process, besides the cheapening of the puddling operation. They are, I think, sufficiently obvious from the facts that one skilled puddler can produce 4,000 lb. of puddled iron every 30 to 45 minutes, or, say, 60,000 lb. in 12 hours; that this iron is in the form of a bloom which is practically homogeneous, is free from laminations, and in a state very similar to that of the slab rolled from a steel ingot; and, finally, that this slab can be rolled or forged into finished product at a loss which will be about 6 per cent. from the pig.

Proposed Standard Specifications for Steel Forgings and Castings.

Discussion of the Paper of Mr. Webster, p. 170.

Gus C. Henning, New York City: In taking up the discussion of these specifications it is necessary that I give definitions of what I understand under the term "Specifications." There may be three kinds, viz.: (1) Specifications in general; (2) Standard Specifications; (3) Standard International Specifications.

1. A *Specification* is a document used in commerce which should clearly define the qualities of material to be supplied by the producer, the tests which shall be applied for their determination, and the methods which shall be applied for the purpose of determining that the entire product shall possess such qualities, properties and finish as are desired. The terms used in such document must be applied in accordance with their strict technical definitions as used by those most conversant with them, and the language should be of such accuracy that there can be but a single interpretation of each and every clause. A specification is a part of a contract, and should be legally perfect and accurate. Inaccuracy of definition and dic-

tion have given endless cause for misunderstanding and lawsuits, and should be avoided.

2. A *Standard Specification* is one in which the requirements have in every case been based on the best current practice adopted by recognized authorities, and which has given uniformly satisfactory results when complied with.

3. A *Standard International Specification* is one which complies with the above requirements, but is also based on the best practice obtaining in all countries and as enunciated by authorities in them.

The latter class is that which concerns us at this time, because the subject under discussion was inaugurated under international auspices for the purpose of being used for and of establishing international specifications. European practice should not be neglected, but full allowance should be made therefor; the specifications should be based on the present state of the art of making steel, and also of the science of testing materials as enunciated by European authorities, who are, without doubt, the recognized leaders thereof.

The specifications in Mr. Webster's paper are wanting in many respects; they prescribe some material which should not be used in any case, specify test-pieces and methods of testing which are unreliable and do not give accurate knowledge; and methods of inspection are practically omitted. The words and language used therein are inaccurate, incorrect and confusing, and well-known technical terms are incorrectly applied.

Their worst characteristic is, however, the fact that in many points they are directly opposed to the interests of the producer, and must cause the rejection of material which will comply with the specification requirements when subjected to proper and correct methods of testing.

The test-pieces and methods of testing prescribed are those which were in common use in this country twenty-five years ago, and I regret that European engineers have, by these specifications, been led to believe that we have learned nothing in this matter in nearly one generation.

I shall now proceed to prove the above assertions, which may appear too condemnatory to many engineers, and will take them up in the order as given above.

1. *Physical Properties and Chemical Composition.*—While the physical properties prescribed in paragraph 3, page 175, and paragraph 4, page 177, may in general be satisfactory, there are two criticisms to offer. The various grades of steel are not sufficiently qualified to insure that one or the other will be produced, because it is nowhere defined between which limits of strength or ductility each grade shall lie. Again, a specification of minimum tenacity of 58,000 lb. and yield-point of 29,000 lb. per sq. in. for *forged steel* is so low that none but very poor steel will show these lower limits.

Another point which should be mentioned is that the processes by which the steel is to be made are prescribed, while this might be wisely omitted. The effect of this will be to discourage the development of new processes, excluding all electro-metallurgical methods which are sure to be developed at no distant date. If the other conditions of these specifications are met, there need be no stipulation as to the method of producing the steel. That will take care of itself.

In paragraphs 2 and 3, page 177, under "*Chemical Properties,*" it is stated that castings which shall not be tested may have $\frac{6}{10}$ more P than those which are to be controlled; again, in the former the limit of S is not prescribed, while in the latter it is; therefore such material not subject to test may contain more injurious components than those which will be carefully examined. This seems an anomaly to me.

2. *Test-Pieces.*—For bending test specimens, 1 in. x $\frac{1}{2}$ in. is prescribed, only two dimensions being given; and hence it is permissible to interpret this specification at pleasure. As the minimum length of a bending test-piece affects the result of a test, it is imperative to state this as well, and the omission of it is inexcusable.

For the tension-test for forged and cast-steel, the use of a test-piece having but a 2-in. gauge length is prescribed, which is that used by the U. S. Navy Department. While such a test-piece of the dimensions given is not used in any other country, it possesses nearly all the bad points which it could possibly have. It is too short; extension is affected by the resistance of the threads; and the results as to strength are affected by the shoulders between thread and gauge mark.*

* Martens' *Handbook of Testing Materials*, p. 87.

In the first place, the cylindrical part should be continued at least ½ in. beyond each gauge-mark; then this should be filleted directly to the threaded shoulders. Any such proximity of shoulders to gauge-marks, as shown, will affect extensions and resistance, and in a manner quite indefinite, depending upon location of fracture.* Unless fracture occurs at the precise middle of length, the extension will be many per cent. less than should be credited to the material.† "In short bars, as used to avoid unnecessary expense, the so-called proportional elongation no longer appears distinctly separated from the local extensibility near the gorge." "If the fracture occurs away from the middle point of the gauge length, elongation cannot be found otherwise than too small . . . ."‡ There is certainly no difficulty whatever in producing, with the castings, test-pieces 16 in. long, gated from them without change of pattern, and cast at the same time. Such coupons would be true samples of the steel, and could be removed and tested after annealing. The provision that the test-piece may be cut from the sink-head is very objectionable because of the possibility of segregation, and of slag and dirt being in it, and because such would produce results against the interests of the producer. The correct shapes of test-bars which will always give correct and comparable results were adopted in Europe many years ago, and should also be introduced in this country.§

3. *Methods of Testing.*—It will be seen that both yield-point and elastic limit are prescribed for forged steel, but only the former in the case of castings; and it must be remembered that these are to be determined on test-pieces of 2-in. gauge length. The former is to be determined "by drop of beam or lag of gauge," and the latter "by an extensometer, attached to the specimen in such manner as to show the change of rate of extension under uniform rate of loading, and will be taken at that point where proportionality changes."

In point of fact, these two points, as here defined, both depend upon the change of rate of extension of the test-piece, and are the same, although given different names. In order to prove this, it becomes necessary to give correct definitions of

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* *Ibid.*, p. 118. † *Ibid.*, p. 120. ‡ *Ibid.*, p. 110.

§ Martens' *Handbook of Testing Materials*, Fig. 107 and p. 135.

these points. In these specifications the yield-point is made to be a function of the testing-machine, while the elastic limit is made to be a function of the testing-machine and of an undescribed apparatus, while they are both really functions of the material itself.

There are three terms used in defining the elastic properties of materials, viz., *proportional limit*, *elastic limit*, and *yield-point*.*

The *Proportional Limit* is that point at which the extension ceases to be proportional to loads applied, and this is determined by measuring the extensions at regular intervals of increment of load. The precise determination of this point is dependent upon the precision of the measuring instrument.

The *Elastic Limit* is that point at which the material first takes permanent set and does not return to its original shape. The precise determination of this point is also dependent upon the accuracy and precision of the apparatus used in determining changes of shape, and is more or less clearly defined in different materials. It can only be determined by successive application and removal of increasing loads, and measurement of the extension and set produced by same.

The *Yield-Point* is that point at which the material shows a sudden rapid increase of extension under increasing load.

There is a ready and accurate method of determining this point by simple means, consisting of a pair of dividers, on which is mounted a reading-glass for those who are not gifted with the best sight. This device, which I have used in my practice for many years, is used in the following manner on test-pieces of proper length: When a piece of forged steel 8 in. long is loaded to its supposed yield-point of 35,000 lb. per sq. in., it will stretch 0.011 in., assuming E = 29,500,000. When the yield-point is as high as 65,000 lb., the test-piece will stretch 0.0176 in. under that stress. Should the material stretch more than these amounts, it is either not up to requirements or the yield-point has been passed.

In order to determine the yield-point, the dividers are set to 8 in., and the 8-in. gauge-marks are placed on the test-piece, as well as another mark 2 or 3 hundredths of an inch within one

* *Ibid.*, p. 30; also Unwin, *Testing Materials of Construction*, pp. 7, 62, etc.

of them. The test-piece is then subjected to load while one point of the dividers is held on one of the gauge-marks; as the material stretches the scribed lines on it still travel under the other point, and as soon as the inner line is reached the yield-point has been passed, which will be made manifest by a sudden rapid extension of the test-piece under the free point of the dividers. It is a well-known fact that the drop of the beam of a lever-testing machine depends upon the inertia of the levers, the rate of loading, and last, but not least, upon the person manipulating the testing-machine. The lag of the gauge of an hydraulic machine, on the other hand, depends upon the speed of loading and the inertia and mechanism of the gauge itself. This will give reliable results only when it is operated very slowly, which is contrary to the present custom of rapid testing now prevalent in this country. In both cases, however, slip of test-piece in the holders vitiates the observations, making them unreliable, and fixing the yield-point at a value lower than the material should indicate, which is against the interest of the producer. In Emery's testing-machines the drop of beam is so indefinite and difficult to observe under ordinary speed of testing that it cannot be used for the purpose intended. The dividers, on the other hand, always permit reliable determination of yield-point, and can be used at any speed of operation of the testing-machine. There is, however, another method by which the yield-point and all other properties of materials can be determined accurately—by autographic apparatus, such as my "Pocket Recorder";* and this, moreover, gives a permanent record of results which, when properly made, are of the greatest value. It will be seen from the above figures that the elastic stretch of test-pieces only 2 in. long will be but one-quarter of the amounts stated, *i.e.*, 0.00275 or 0.0044, which are dimensions so minute that they cannot serve practical purposes or be observed by the naked eye or even a reading-glass. The dividers cannot, therefore, be used on these short test-pieces.

The compilers of these specifications know that this minute extension of 2-in. test-pieces does not produce drop of beam or lag of gauge, as is the case with 8-in. lengths, and hence specify

* *Trans. Am. Soc. Mech. Eng.*, vol. xviii., p. 823 (1897).

the determination of what they call "elastic limit," which, by the method prescribed for its determination, might be the "proportional limit," but is actually the yield-point, as it is located at that point at which the pointer of the extensometer suddenly moves much more rapidly, *i.e.*, at which the test-piece suddenly stretches rapidly. There are two other means by which the yield-point of 2-in. test-pieces can be determined, viz., by accurate measuring-instruments correctly designed, and by recording apparatus which produces a diagram recording extension up to and beyond yield-point multiplied 40 times. This latter diagram will then be the same as that obtained from an 8-in. test-piece multiplied 10 times, which has been declared "sufficient for practical purposes."* Apparatus sufficiently accurate for determining the yield-point in a rapid manner are duplex roller extensometers.† ‡ § . . . . Any simplex roller extensometer or other apparatus is not sufficient for the purpose, as they will as often give results too low as too high, because they are at first affected by that element of the surface of the test-piece which begins to stretch more rapidly than the opposite one. This has been clearly demonstrated repeatedly, and hence simplex instruments which never can indicate the true axial changes of length of test-pieces are of little value and unreliable.|| Yielding generally begins at shoulders, and the nearer these are to the gauge-marks the sooner will the apparent (but erroneous) yield-point be indicated by the apparatus. In the case of the 2-in. test-piece in which the shoulders are but $\frac{1}{8}$-in. from gauge-marks, this will again indicate a lower yield-point, to the detriment of the producer. There is another point, however, in which the 2-in. test-piece does not permit correct determination of quality of material, viz., elongation. The test-piece is so short that the elongation is seriously affected by the constraint due to shoulders, and the only correct method for determining elongation cannot be applied. "Under the practically permissible assumption that deformations are symmetrical about the point of rupture, there is one method of procedure which gives accurate values for extensibility of materials

* Martens' *Handbook of Testing Materials*, p. 605.

† Unwin's *Testing Materials of Construction*, p. 191, and Martens', etc., p. 546.

‡ *Ibid.*, 606. § *Trans. Am. Soc. Mech. Eng.*, vol. xxiii., p. 648 (1902).

|| Martens' *Handbook of Testing Materials*, pp. 90–94.

under all conditions."* If the fracture is not located at the center of the test-piece, the error due to direct measurement of extension between gauge-marks may be as much as 9 per cent., because the short end has not stretched the normal amount, and hence gives a result against the interest of the producer. The only proper way of measuring extension is to divide the gauge-length into 20 parts, each about 0.4 in. long for an 8-in. length.† Much larger divisions will not answer the purpose. Now, when the fracture is not located at the center of length, then the extension of an equal number of parts located symmetrically either side of it is measured, and to this is added twice the extension of a number of divisions on the long end of the test-piece immediately adjoining those already measured, and equal to one-half of twenty less the number already measured. Thus, in case the extension of three divisions either side of the fracture is measurable, then twice the extension of the adjoining 7 divisions is to be added, to give the total extension of the gauge-length. When this method is not employed, the results will invariably be against the interests of the producer, because the short end, stretching less than the normal, produces an apparently smaller total extension. This method of determining extension by proportional parts cannot, of course, be used on 2-in. test-pieces.

I think I have now clearly shown that a 2-in. test-piece is wrong and unreliable from every point of view, and that one more detrimental to the interests of the producer could not well have been selected. There is but one plausible reason which might make a short test-piece seem desirable, viz.: that it can be more readily cut from a forging, and cause less waste and expense. If it be borne in mind that the purchaser should and does actually pay for all testing in the end, whether he knows it or not, the manufacturer should always leave enough stock to provide for test-pieces of the standard length of 8 in., because it would be entirely to his own interests from every point of view. Moreover, as standard specifications do not refer to specialties, but to the great bulk of material ordered in large masses and quantities, a few extra pieces of greater length, paid for by the purchaser, will satisfy all inter-

* *Ibid.*, p. 111.

† *Ibid.*, 157.

ests and not materially increase the cost of production. Shafts, cylinders, anchors, piston-rods, ship-forgings, frames, etc., could all be so made as to provide proper crop-ends for 8-in. test-pieces in a simple manner. Wheel-tires and the like must, of course, be classed as specialties, and treated as such. In Europe, 8 in. (200 mm.) has been adopted as the standard length, and on the Continent no careful engineer any longer thinks of measuring extension except by the method of proportional parts.

The method prescribed for making the bending tests is also contrary to good practice, and against the interest of the producer.

It is stated that "this specimen . . . . shall bend around a diameter" . . . . and that the test may be made by "pressure or by blows." It is not stated that the specimen shall be bent around a bar, pin, or plug of a certain radius of curvature, but merely bent around the abstract idea of a "diameter." Now, it makes a great difference in results whether such piece of material has been bent free or around a resisting object of definite curvature, and the latter will be a more favorable test, and one which the producer should demand. Bending free does not bend the material to any definite curvature, but to any kind of irregular shape, frequently producing a sharp kink at center. Again, it has been demonstrated that bending material "by blows" is most unreliable, and has frequently caused unwarranted rupture. This method is, again, directly against the interests of the producer.

In order to make a satisfactory bending test, it is necessary to use a test-piece of proper pre-determined shape (including length), and then to bend it slowly around a resisting object of prescribed curvature. This alone will truly characteze their material and be a test fair to the producer. Machines for this purpose have long been in the market. Any other bending test should be abolished.

As this method may appear to involve additional expense, I must add a few words about the expense of testing.

The testing laboratory in every works should be as profitable to the producer as every other department of the works. There is no reason why tests should not always be made at the expense of the purchaser. I would go further than this, and

advocate that all material used for test-pieces should be charged up at contract price against the purchaser. These specifications should contain such clause. He who then desires to know his material thoroughly will pay somewhat more for the confidence he will possess in his material than the one who accepts it on the face value of an attested certificate of tests furnished free by the producer. On the other hand, the producer will make money out of the testing laboratory, and can equip one of sufficient completeness to serve every purpose, and this at the cost of his customers. This would be the only just and equitable manner of providing for proper testing for commercial purposes.

4. *Inspection*.—The single clause in these specifications referring to inspection says that "the inspector representing the purchaser shall have all reasonable facilities afforded him by the manufacturer, to satisfy him that the finished material is furnished in accordance with these specifications." May I ask how many opinions may exist as to what might be called "reasonable facilities?" Moreover, this paragraph distinctly states that these facilities shall be afforded to satisfy the manufacturer that the material is furnished in accordance with these specifications. It may not be so intended, but any one honestly reading this sentence must agree with me that my interpretation is correct. This clause should read, "The manufacturer shall at all times furnish promptly to the purchaser or his representative all facilities necessary to test and inspect every part of all material produced under the contract." Furthermore, it should be stated that all material shall be handled in such manner that it can be subjected to surface inspection on both sides in all cases; and that no material shall be shipped until the acceptance mark shall have been affixed thereto. Provision should also be made for daylight inspection; for, in spite of many statements to the contrary, no person can readily detect seams, coldshuts and checks by use of artificial light with its many vagaries, variations and shadows.

I could enumerate many other points which my experience has taught me to be essential,—not for the purpose of embarrassing the producer, by any means, but merely to exclude any accidentally defective material, which may cause very grave consequences.

5. *Inaccurate Language.*—While I have already pointed out the incorrect use of several technical terms, I must call attention to others, which should be rectified or eliminated.

The term "*chemical properties*" is used instead of "*chemical composition*" in the specifications for cast-steel. "*Drop test*" and "*percussion test*" are used in speaking of tests which are well known under the names of "*breaking test*" and "*hammer test*," while the terms used are in general use for other clearly-defined and well-known tests.

In another case it is prescribed that "*the test-piece may be turned parallel throughout its entire length.*" This probably means that the *test-piece may be turned truly cylindrical throughout its length*, because that is what is meant; but it certainly does not define either the process or the intention.

It would lead too far to take up every point in these specifications which may be justly criticised; and I shall, therefore, abstain from further comment, hoping that what I have presented will produce a thorough revision and secure specifications which will be a credit to American engineers from every point of view.

William Kent, New York City: The only criticism I have to offer is concerning the specifications for yield-point and elastic limit. If the yield-point of boiler-plate and forgings of "soft or low-carbon steel," and of "carbon steel not annealed," is specified as low as 50 per cent. of the tensile strength, what is the use of specifying it at all? Any forged or rolled steel which will fulfill the specified requirements of tensile strength, elongation and contraction of area, will also show a yield-point exceeding 50 per cent. of the tensile strength.

Why is the yield-point specified for some of the varieties of steel forgings and not for others?

If the elastic limit is to be determined by an extensometer, and is defined as that point where the proportionality changes, it is a very uncertain quantity, and its value varies greatly with the delicacy of the instrument used and with the personal equation of the observer. It would be much better to use what the late Prof. J. B. Johnson* called the "apparent elastic limit,"

* *Materials of Construction*, p. 19.

which is thus defined: "The apparent elastic limit is the point on the stress-diagram at which the rate of deformation is 50 per cent. greater than it is at the origin." An equivalent definition, which does not involve the stress-diagram, is that point in the test at which the modulus of extension (length $\times$ increment of stress $\div$ increment of elongation) becomes two-thirds of the maximum; or, still better, when applied to steel, that point at which the elongation in eight inches per 1000 lbs. of added stress per sq. in. first exceeds four ten-thousandths of an inch. If the modulus of elasticity of steel is 30,000,000, the elongation of an 8-in. specimen for 1000 lbs. of load per sq. in. is $8 \times 1000 \div 30,000,000 = 2\frac{2}{3}$ ten-thousandths of an inch. When the rate of deformation (elongation) becomes 50 per cent. greater, the modulus of extension is 20,000,000, and the elongation per 1000 lbs. of added stress per sq. in. is $8 \times 1000 \div 20,000,000 = 0.0004$ in.

The use of this "apparent elastic limit" would avoid the difficulty of determining the so-called true elastic limit, or the point where the proportionality changes.

If the yield-point is to be determined by the "drop of the beam," it will vary with the speed at which the testing-machine is run. The specification should include some direction for diminishing the speed to a very slow rate (say a rate equivalent to that which will produce an increased stress not greater than 5000 lbs. per sq. in. in one minute) between a point in the test at which the stress is not more than half the probable tensile strength and the yield-point.

Principles Controlling the Geologic Deposition of the Hydrocarbons.

Discussion of the Paper of George I. Adams, p. 340.

DAVID T. DAY, Washington, D. C.: The paper of Mr. Adams is chiefly valuable because it emphasizes the ease with which petroleum can migrate in the earth's crust. Concerning this migration, I have little faith in the *rôle* of water as a carrier of gaseous or liquid hydrocarbon, suspended or mixed in the water in any way. My lack of faith is due to observation of

changes which take place when petroleum moves through a porous solid. Several years ago, when watching the commercial methods of filtering certain petroleum products through fuller's earth, it was evident that the first filtrates had a markedly lower specific gravity, and were much more fluid than what came through afterward, although the petroleum product was filtered while hot and perfectly fluid. In other words, the homogeneous solution of various hydrocarbons, when diffused through a layer of fuller's earth, separated into various fluids. The fluids of least viscosity traversed the fuller's earth with the greatest speed, and were, therefore, the first to filter through. The separation was, of course, not sharp, and the filtrates were simply mixtures in which those coming through first contained a large proportion of less viscous hydrocarbons.

After repeating experiments on this method of fractional filtration, I applied it to crude petroleum, with the result that, starting with black varieties, the first filtrates obtained by diffusion through fuller's earth were colorless, and much more volatile than those which followed. The latter fractions shaded in color to that of the original black material. By extracting with ether the portion of the crude petroleum left behind in the fuller's earth, vaseline was obtained. The fractions obtained in this work were so similar in color, specific gravity, etc., to the many varieties of crude petroleum found in Pennsylvania as to suggest that these different varieties of petroleum had resulted by the upward diffusion of petroleum through close-grained shales. The original source from which it came is deeply seated, and quite possibly it came from reservoirs of petroleum in Trenton limestone underlying the reservoirs in which petroleum is found in Pennsylvania. It was suggested that this original petroleum might be the same in character as that found in Ohio. These views were contributed to the Franklin Institute in a discussion of the origin of petroleum. They were further developed in a paper on this same subject presented at the International Petroleum Congress at Paris in 1900, and received some additional support from an experiment showing that powdered Devonian shales have the same property of filtering oils as fuller's earth, but to a markedly less extent.

It is to be noted that, utilizing this same capacity of fuller's earth for fractionally separating petroleum, Mr. Clifford Rich-

ardson has succeeded, by the use of an apparatus referred to in my article before the Petroleum Congress, in fractionizing crude petroleum from Beaumont, Texas, so as to separate sulphur therefrom,—to which achievement it is especially interesting to refer, inasmuch as it makes the original identity of Ohio and Pennsylvania oils much more probable.

Mr. Adams leaves us with the impression that water might diffuse through porous rocks, carrying mixed with it small quantities of petroleum. Inasmuch as the diffusion of petroleum through shales is accompanied by a partial separation of the constituent oils, the probability is very great that a diffusion of a mixture of oil and water would result in prompt separation of the oil from the water.

Mr. Adams: The information as to the behavior of petroleum which has been contributed by Dr. Day is especially valuable and suggestive; but in view of the fact that in his experiments the fuller's earth and powdered Devonian shales through which the oil was filtered were dry, the experiments do not have a direct bearing upon the underground circulation of the hydrocarbons in the presence of water. It is the behavior of the hydrocarbons with respect to water which I am attempting to emphasize. That there is a certain intimate relation possible between oil and water can scarcely be denied by any one who has noted the ease with which water is contaminated by petroleum-products.

The Secondary Enrichment of Ore-Deposits.

Discussion of the Paper of S. F. Emmons. (See *Trans.*, xxx., 177.)

(New Haven Meeting, October, 1902.)

George Smith, Sydney, N. S. Wales (communication to the Secretary): The very interesting paper by Mr. Emmons on "The Secondary Enrichment of Ore-Deposits" has just come under my notice; and its reference to my own paper* on "The Ore-Deposits of the Australian Broken Hill Consols Mine"† is therefore only noted some two and a half years after its publi-

* *Trans.*, xxx., 204–5.

† *Trans.*, xxvi., 69.

cation. I regret the delay, and will now hasten to inform Mr. Emmons that the possibility of enriching solutions having passed into the lode through the cross-veins certainly received consideration at the time the ore was found, especially as it seemed the most feasible method of accounting for the successive layers of ore illustrated. But, as I shall show, the available evidence was opposed to such a conclusion. Several "indicators" were subsequently found which could not be termed "cross-veins," as they did not possess continuity in any direction, though they were connected with smaller deposits of similar ores under circumstances which left no doubt of an essential connection between them. As a rule, these "indicators" assumed the form of quartz enclosures in the hanging-wall, and the ore occurred at their junction with the lode. When broken into they appeared to be of local occurrence, and, therefore, could not have served as channels for the passage of ore-bearing solutions. They sometimes assumed a fairly direct line over considerable distances, showing only at intervals, the intervening spaces of the lode being barren. The most distinct of these "indicators" was a well-defined leader of opaque, white quartz (the indicators are generally greenish and semi-transparent), about 6 or 8 feet long by about 3 inches thick, which described a slight curve as it fell obliquely on the lode. Following the exact line of intersection, a trace of silver-ore was found which began and ended with the quartz. The ore was argentite with a little pyrargyrite (pseudomorphous after dyscrasite). The antimony had partially separated as a powdery white oxide. On breaking into the hanging-wall the quartz was found to be non-continuous, as was also the joint in which it existed, and the explanation suggested was that it occupied a fracture in the rock, which, at the time the silver was deposited, had been filled by a solution which had conveyed, or supplied, the conditions necessary for precipitation at the contact.

Such rock-joints or fractures were common during my later connection with the mine, but in only one instance were they known to contain a metallic substance. In this a thin seam of siliceous silver sulphide was followed vertically into the hanging-wall for several feet before giving out. It was not more than an inch in thickness, and was associated with a little

limonite. The joint continued above and beyond the point explored.

To prove whether any overlying vein existed from which the silver could have passed through the large cross-vein shown in my paper,* a rise was put up on it for about 60 feet, immediately above where the largest and richest mass of ore was found, but nothing was seen to indicate the existence of such a vein. It was unnecessary to continue the rise to the surface, because an air-shaft in the vicinity, also on the cross-vein, had given negative results. No second lode from which the silver was likely to have been derived was known to exist in the locality, and it would therefore seem reasonable to assume that the silver was originally contained in the solutions of the lode in which it was found.

As stated in my paper, the electro-magnetic theory of deposition was advanced to account for the occurrence of the dyscrasite; as, without the aid of some such influence, it seemed difficult to understand how the chemical combination of the silver and antimony had been so extensively brought about. I regret that Mr. Emmons appears to have overlooked this explanation, as an opinion upon the subject from such an eminent authority would be of very great interest.

There appears to be some confusion in regard to the distribution of the silver minerals at Broken Hill. Dyscrasite, stromeyerite, etc., were not found in the kaolin of the Proprietary mine, as stated by Mr. Emmons. As a matter of fact, it is extremely doubtful if any of the minerals mentioned were found in that mine; but, with the exception of polybasite, all occurred in the Consols mine, which is situated on the plain in the vicinity of Broken Hill.

I would take this opportunity of referring to the excellent paper on Broken Hill by Professor Beck,† in which garnets are mentioned as occurring in the Consols lode. The latter is unquestionably a fissure-vein, and the importance of such a discovery will commend itself to those who are interested in the occurrence of the garnet. Professor Beck says:

"In a piece of ore from the Consols mine, lying before us, we observed under the microscope a granular crystalline aggregate of quartz-veins, between which

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* *Trans.*, xxvi., 73, Fig. 1.

† *Records Geol. Survey*, N. S. W., 1900, vol. vii., Part I., p. 28.

lie irregular patches of galena, sulphide of zinc and iron pyrites. A few garnets are also interspersed among the quartz; but, besides these, galena and well-defined little crystals of garnet also occur as inclusions within the quartz, which latter has the structure of the Broken Hill quartz illustrated by us."

Without in any way intending to question the accuracy of this determination, I venture the opinion (based upon close observations extending over eight years) that the sample referred to is mistakenly described as coming from this mine. The lode material differs widely from that of the Proprietary lode, and no garnets were ever detected in the vein-filling; moreover, blende, though present in quantity in the larger cross-vein, was not known to occur in the lode up to the time of my leaving Broken Hill, in 1898.

Mr. Waldemar Lindgren, in his valuable paper on the "Metasomatic Processes in Fissure-Veins,"* remarks upon the novelty of the garnet occurrence as reported by Professor Beck. Perhaps a confusion in labeling has led to a misconception; this seems the more probable, as Herr Gmehling, who supplied some of the samples examined, received, whilst at Broken Hill, examples from both mines from me, though exactly what they were I do not now remember.

S. F. EMMONS, Washington, D. C. (communication to the Secretary): Mr. Smith's remarks furnish proof of the truth of my statement, when referring to his paper, "that it is unsafe to theorize on the observations of others." Anyone, even with the best intentions, is liable to give an incomplete, or even false, impression with regard to the facts, as I seem to have done on this occasion. I did not discuss his hypothesis of electro-magnetic currents for the reason that, on the few occasions I have had to obtain experimental tests as to the existence of such currents in connection with ore-deposition, the results have been negative; and Mr. Smith had offered nothing more than the suggestion of such an agency, without presenting any facts to support his hypothesis. I was willing to admit the possibility of such currents for argument's sake, but offered the suggestion, as susceptible of more definite proof, if the examination was made with this idea in mind, that the richer minerals may have been precipitated at the intersection of the indicators

* *Trans.*, xxx., 611.

with the main fissure as the result of interaction between solutions of differing composition. This explanation had, it seems, occurred to Mr. Smith when he broke into the "well-defined leader of an opaque, white quartz," but was later abandoned, for some reason which does not appear to me entirely clear.

I did not conceive it to be essential that these cross-veins actually furnished the silver, and I admitted that the local enrichment might have come from ascending as well as from descending solutions. The cross-veins would have simply furnished the precipitant; it might have been in the form of a solution of differing composition from that which followed the main vein; or, as in the case of the indicators of Ballarat, simply as barren pyrites, in contact with which, solutions carrying sulphur salts and coursing along the vein-fissure would have deposited part of their silver contents.

Section Across the Sierra Madre Occidental of Mexico.

Discussion of Mr. W. H. Weed's paper. (See *Trans.*, xxxii., 444.)

BY G. C. HEWETT, COLORADO SPRINGS, COLO.

In traversing lately the Sierra Madre, west of San Pedro and Guanacevi, I estimated the topographic summit at several points, by aneroid barometer, at about 8,500 ft. Mr. Weed's measurements, 40 miles further north, are from 9,000 to 9,500 ft., and indicate the correctness of the impression I obtained at the time, namely, that the greatest movement in the elevation of the Sierra was between Guanacevi and Guadaloupe y Calvo. This is suggested also by the course of the headwaters of the Rio Conchas and of the Nazas, and by the relative corrasion of the branches of the two streams. Mr. Weed's statements as to the unevenness and great relief of the andesite floor underlying the later dacites and rhyolites are very interesting, and lead me to add that the floor of the andesite breccias and flows is uncovered for several square miles east of Guanacevi. This floor is of reddish, bluish and gray shales, lying horizontal or dipping slightly east. Their age is unknown; but from the interbedded occurrence of copper sulphides, I took it to be Triassic,

by reason of the numberless similar occurrences, referred to that age, in New Mexico, Colorado, Utah and Wyoming.

The similar, though larger, bedded deposits at Las Vigas, Mr. Weed places in the Comanche formation of the Cretaceous. The Sierra Madre at San Pedro is the dissected plateau described by Mr. Weed, and sinks gradually southward until at Durango its elevation cannot be much greater than 7,500 ft. The spring-water supply at Durango eventually finds its way into the Rio Mesquital and thence into the Pacific ocean. That this river has preserved its course during the elevation of the Sierra is another indication that the movement there has been smaller than it has been in the north. The drainage between the Nazas and Durango is into *cienagas* or old lake-beds. Around the largest *cienaga*, east of Durango, is an old graded wagon-road, which, tradition says, was built by the soldiers of Cortez around a lake which was at that time impassable. To-day the bed is fine pasture-land, with not even a marsh, except in very wet seasons. If this be true, as it appears to be, 400 years have seen a great dessication of the country.

The Mineral Crest, or the Hydrostatic Level Attained by the Ore-Depositing Solutions, in Certain Mining Districts of the Great Salt Lake Basin.

Discussion of the Paper of W. P. Jenney, p. 46.

George Otis Smith, Washington, D. C. (communication to the Secretary): The somewhat exceptional features discussed by Dr. Jenney in his paper on "The Mineral Crest" were recognized and described by Mr. Tower in our report on the Tintic district. The general absence of surface-outcrops of important ore-bodies, and their occurrence, when present, at relatively low points, are noticeable characteristics of this district, and the statements made by Dr. Jenney agree in general with our observations. The approximately horizontal upper limit of the Silver Gem ore-body in the Bullion-Beck mine is figured in this report, and mention made also of the horizontal pipes of ore found in several mines.* In only one case,† however, was any hypothesis

* Tower and Smith, "Geology and Mining Industry of the Tintic District, Utah," *19th Ann. Report, U. S. G. S.*, Part III., p. 710.

† *Op. cit.*, p. 751.

presented to account for this horizontal character of the ore-body. In the Sioux and Utah mines, the parallelism of the ore-body with bedding-planes suggests an explanation for the horizontal crest, that however would not apply elsewhere.

Facts which bear on Dr. Jenney's hypothesis, and may be used to test it, are found in the Eureka zone in the Tintic district. Here in three mines, Centennial Eureka, Bullion-Beck and Gemini, whose workings connect, there occur ore-bodies which, though distinct, are located on the same general system of fissures, and these are found to have quite well-defined horizontal crests of the character described. Within a distance of less than half a mile there is a difference in the upper limits or crests of these three adjacent ore-bodies amounting to 900 ft., a vertical range which seems too great to be referred to any definite hydrostatic level.

Another line along which Dr. Jenney's paper may be discussed is that of the conditions under which ore-deposition took place in this region. This discussion may also serve to illustrate how essential is a complete understanding of the geologic history of the area to a study of ore-deposits. Facts which seem to possess only a scientific interest may prove later to have a direct bearing upon important hypotheses, such as the one presented by Dr. Jenney. The sequence of geologic events as given in the paper here discussed is:

(1) Volcanic disturbances causing elevation and folding of the sedimentary rocks.

(2) Wet climatic conditions, with consequent extensive erosion.

(3) Deep-seated disturbances forming the fissures and inducing ore-deposition.

(4) A slight amount of later erosion.

The geologic history as interpreted by Mr. Tower and myself, from the results of geologic mapping of an area of over 200 sq. m., as well as the more detailed study of the mining district itself, is quite different. It may be briefly stated as follows:

1. Elevation of the region, with folding of the Paleozoic sedimentary rocks, fissuring and ore-deposition.

2. Erosion, which began with the Mesozoic uplift and continued into the Tertiary, producing a surface with greater relief than that of to-day.

3. Tertiary volcanic activity, the earlier rhyolitic lava filling deep cañons, on the slopes of which talus containing ore-fragments was cemented by the lava, the later andesite lava-flows largely rejuvenating the deeply-eroded mountain range.

4. Fissuring and ore-deposition in the more compact igneous rock, with possible additional mineralization of the sedimentary rocks, as suggested by Mr. Emmons.*

5. Erosion, by which great masses of igneous rocks have been removed, with only slight changes in the topography of the limestone ridges, which had been buried by the lavas.

Comparison of the two interpretations shows a considerable absence of agreement as regards the sequence of geologic events. The occurrence of ore-fragments in the pre-lava talus is directly opposed to the recent age given by Dr. Jenney to these ore-deposits of the sedimentary rocks. It seems probable also that hundreds, if not thousands, of feet of strata may have been removed here since the principal period of mineral-deposition closed, so that in this respect the Tintic is not different from other mining districts. If, however, the mineralization even took place in the latter part of the period of erosion that preceded the volcanic activity, it is again true that the present topography of the region is far from being what it was at that time. The upper part of Eureka Gulch is still filled with rhyolite, so that the pre-lava cañon was deeper than the present gulch, and may have drained eastward instead of westward, as at present. These topographical relations would involve surface outlets below some of the mineral crests in this vicinity. It appears, therefore, that the present arid climate has not prevailed long enough to make the question of ore-deposition so exceptionally simple in the Tintic region; and if Dr. Jenney's hypothesis of the hydrostatic origin is to be accepted for the mineral crests, reference must be made to a topography quite different from that of the present and much more ancient than he has suggested.

S. F. Emmons: Whether such mineral crests as Dr. Jenney describes are of common occurrence remains yet to be proved. It is well known that there are many ore-bodies that do not outcrop at the surface; but I do not recall a single one, out-

* Text, Tintic Special Folio, No. 65, Geologic Atlas of the U. S.

side of the Tintic district, of which any such relations can be predicated with respect to the erosional forms on the surface, as Dr. Jenney's theory demands. I should say that original deposits, formed since the present topography has been sculptured, must be of very rare occurrence.

Dr. Jenney's theory to account for the conditions he describes does not impress me favorably; for I doubt if the circulation of mineral-depositing waters in fissures is subject to the run-off of the neighboring ravines. And again, in the cases where the fissure reaches the surface, and is recognized by deposits of quartz, barite, etc., it is difficult to conceive of such selective chemical action as would stop the metallic minerals in the ascending solutions at a given level while the others went on to the surface. In such cases, it seems that a more plausible explanation might be looked for in the action of descending surface-waters.

A Consideration of Igneous Rocks and their Segregation or Differentiation as Related to the Occurrence of Ores.

Discussion of the Paper of J. E. Spurr, p. 288.

Alexander N. Winchell, Butte, Mont. (communication to the Secretary): Mr. Spurr calls attention to the fact that an ore-deposit may be due to a succession of concentrations at different geological epochs. He cites an example of such a condition on Napoleon creek, a branch of Forty-Mile creek, Alaska.

It will perhaps be of interest to call attention to another example of the same general character, not so remotely situated. The example referred to is located on Pole creek, a tributary of Cherry creek, in the extreme northeastern part of Madison county, Montana. An excellent geological map of this region is to be found in the Three Forks folio (No. 24) of the United States Geological Survey. According to this map, Pole creek, in its upper course, occupies the contact between the "Flathead" formation, which Peale correlates with the Middle and Lower Cambrian, and an area of gneisses and schists supposed

to represent the Archean. A visit to the region last summer enabled the writer to determine the presence of a thick conglomerate formation between the Flathead and the Archean. The conglomerate in question has an outcrop along the southwest side of Pole creek varying from one-half to one mile in width; its maximum thickness in this region is at least 500 feet; lying conformably above it are 300 or 400 feet of schists, fine sands, etc. It may probably be correlated with the "Belt" formation of Peale, as it lies unconformably upon the schists and gneisses of the Archean, and is overlain (above the fine sands), apparently unconformably, by the Flathead formation. It seems to be auriferous throughout its extent, and somewhat richer at the immediate surface.

Let us outline, now, the successive concentrations of gold in this district. The igneous rocks of Madison county certainly belong to a "metalliferous province" rich in gold; but to consider that the province is due to segregation from an originally homogeneous magma seems to the writer to be straining the theory of differentiation considerably beyond the breaking-point. As pointed out by Fouqué,* we have no evidence that such a primitively homogeneous magma ever existed; on the contrary, the marked heterogeneity of meteorites argues that cosmic materials are far from homogeneous.

Omitting, then, from the series, Spurr's concentration by magmatic segregation, which in this case one would probably have to refer to Archean time, we have: (1) mechanical concentration by surface-waters (ocean conglomerates and gravels —probably pre-Cambrian); (2) residual concentration by surface-waters due to disintegration and erosion; and (3) mechanical concentration by surface-waters producing stream placer-deposits.

It seems just possible that the same conglomerate caps the so-called "Gravel Range" about the head-waters of Alder creek (about thirty miles distant as the crow flies), in which case it probably aided in the formation of the famous Alder Gulch placer-deposits.

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* *Bull. Soc. Fr. Minéral.*, 1902, xxv., p. 349.

The Chemistry of Ore-Deposition.

Discussion of the Paper of Walter P. Jenney, p. 445.

BY JOHN A. CHURCH, NEW YORK CITY.

PROFESSOR JENNEY has performed a notable service in presenting this summary of the steadily increasing body of observation on the presence of carbon in rocks of all kinds and its probable influence upon ore-deposition, and in formulating a mode of comparing directly the relative resistance of minerals to oxidation, as well as their reducing-power, and the protective action which minerals having higher reducing-powers exert in preventing the oxidation of associated minerals which possess relatively lower affinities for oxygen.

I have had an opportunity of observing a vein which falls within the scope of his interesting discussion. The vein at Ku Shau Tzu, Mongolia, lies directly across a contact of limestone and overlying bituminous shales. Probably it occupies a compression-fissure. The shale has been reduced to such a condition of non-coherence that much of it can be crushed in the hand, producing a handful of angular fragments resembling beech-nuts in shape and size.

In the limestone the metals are principally in argentiferous galena with some pyrite and blende; but the latter two are very subordinate in quantity to the galena. In short, it is an every-day lead-vein in limestone, with siliceous limestone gangue. It is one of those veins in which the ore is not continuous, but consists of a band in the country-rock in which seams of lead sulphide begin at one wall and cross in a bent form, increasing in thickness, to the other wall, where they thin out and end. This may indicate torsional stress, but the shape of the lenses points to some other action. They often ran nearly parallel to the hanging-wall for a considerable distance and crossed the vein on a moderate angle, but turned sharply along the vein on approaching the foot-wall. The intermediate rock contains nodules, bunches and specks of ore, and the lenses vary exceedingly in size, shape and position in the vein.

In the bituminous shale the deposition of ore is not at all like that in the limestone. The minerals in the shale are tetrahedrite and native silver, the latter occurring in fine scales and sheets of pure metal, weighing from 50 to possibly 100 oz. I cannot speak of these larger sheets from much acquaintance, for all but one of them were stolen by the miners, but the metallic silver in scales and sheets was an important part of the ore.

It is necessary to exclude the notion of secondary deposition at Ku Shau Tzu, because the influence of the shale with its superabundant store of powerful reducing-agent should have gathered to itself every metal taken into solution by descending surface-waters. Whether that was the case immediately at the surface I do not know, as the mine was an old one when I first saw it. The absence of galena, blende and pyrite from the shale, at depths of 300 and 400 ft., indicates that secondary deposition, if present at any time, did not reach so far; and this was to be expected from the reducing-power of the shale at the surface.

I considered that the conditions indicated deposition from a solution rising through the limestone first and afterward through the shale which once covered the lime-rock, though now it is tilted and partially eroded. The limestone precipitated what it could, and the abundant store of carbon in the shale perhaps took the last traces of metal. But this explanation is not without its difficulties when applied to the limestone, however confident we may be of the reducing-powers of the shale.

The feeble reducing-power to which galena yields—only 3.35 per cent. of H, according to Prof. Jenney—explains its presence in the limestone well enough, but why should this rock precipitate also blende (8.25 per cent.) and pyrite (11.67 per cent.), while it left tetrahedrite (6.39 per cent.) to the shale? The reduction of metallic silver in the shale is, of course, not surprising.

There must have been some other selective agency than mere position or the chemical energy of carbon at work to produce these effects. The same considerations lead us to doubt that there was an interchange of elements between different parts of the ascending column of mineral solution, by which the com-

plete precipitation of any mineral in one rock, the shale, for instance, would so dilute the mother-liquor there that this mineral would pass by diffusion from the solution going through the limestone to that in the shale. Such action is familiar in chemical work. When a drop of reagent causes partial precipitation, the remainder of the dissolved substance is diffused immediately through the whole body of liquid. This could not have taken place at Ku Shau Tzu without producing more abundant deposition in one of the rocks than in the other, according to its precipitating energy, and the phenomenon there is not quantitative, but selective, concentration. The quantity of mineral was greatest in the limestone.

It is conceivable that the deposition of ore in the shale would liberate carbon, which, going into solution, might reach the limestone and there act upon the advancing ore-solution, thus giving the shale a large radius of action, and making it contribute to deposition in the neighboring rock.

This question of interchange of elements between solutions, or diffusion, is of great interest and importance, and though it is not germane to the subject of Prof. Jenney's paper, I may be permitted to point out that some observations indicate that there is no horizontal diffusion or exchange of dissolved substances between the two halves or ends of the moving column of solution, which we may consider conveniently to have the same length as the vein. There is evidence that the solution from which an ore of general average composition is deposited may produce ore-bodies that vary in their different parts in a manner important to the miner if not to Nature.

In the well-known case of the Crown Point-Belcher bonanza, one-half of the ore-body contained more gold in proportion to silver than the other half, and the difference was not fortuitous, but persisted through the whole extent of the bonanza. The country-rock was eruptive, the mass of the deposit was silica, the total length was only 500 ft., and it is difficult to see how there could have been selective deposition from a uniform solution. Granting that the difference began at the point where the solution was formed, this difference in the two halves of the current must have been preserved throughout its wanderings,—a proof that there were no exchanges between the two halves.

Of course, if lateral secretion in its first and most restricted sense were true, and the ore were derived from the immediate walls of the vein, an explanation might be found. This extremely limited conception is, I believe, entirely abandoned; and the persistent difference of the Crown Point-Belcher solution along adjacent vertical and, perhaps, horizontal lines of travel, possibly to great distances, is an unexplained phenomenon. Other cases are known in which the facts indicate that there was no exchange of elements between the parts of the common solution from which the respective ends of the ore-body were formed.

It is not probable that the north and south ends of the Crown Point-Belcher ore-body differ in date, for the mass was decidedly lenticular, very thick in the middle and thinning out in all directions. The natural conclusion is that the action, being a replacement of country-rock, began in the central portion of the mass, and the greater thickness there is the effect of longer action. This is equivalent to saying that the action was continuous over the whole of the steadily increasing vein-area, and that ore was forming in the center while it was forming at both ends.

Occurrences of this kind have an obvious bearing upon the views which Prof. Van Hise has expressed upon the movement of waters in the rocks. A natural explanation of the Crown Point-Belcher case is that the thin-leaved porphyry of the Comstock offered a means of ready flow which operated as a channel, to which waters from widely different sources of origin were directed; but this only emphasizes the fact that the two currents maintained their individuality through long wanderings, and even when joined in a channel of limited section. It also implies that gold and silver can be picked up anywhere in the middle of the earth, a conclusion which cannot be admitted; for it is probable that the solution of metals is as selective and phenomenal as is their deposition.

Differential deposition, as in this case, necessarily brings up the question of electro-chemical action; but which way would it work, for or against differentiation? My impression is that it would act for uniformity, and there is no evidence that electrical action in the rocks is strong enough to move a metal or salt through 500 ft. of minute channels.

Prof. Jenney's description of the ore-deposition in the Tintic limestones may be accepted as accurate for the galena of the celebrated "Emma" mine, in Little Cottonwood Canyon, Utah. I well remember a large mass of galena there, almost pure in the center, and surrounded by a thick mass consisting of decomposed limestone fragments in galena, graduating to enclosures of galena in limestone as the distance from the center increased, and ending with scattered, small impregnations of galena in the nearly unaltered limestone walls. The angular shape of the inclusions mentioned by Prof. Jenney was noteworthy there also.

Every mining engineer will recall from his own experience occurrences which sustain the general position which Prof. Jenney takes in reference to the presence of carbon in the rocks of mining districts. One of the problems at Tombstone which the new owners are attacking with such faith is the future of the Contention vein, where it passes through the Lucky Cuss limestone, which is strongly fetid for 100 or 200 ft. in thickness. It may be years before it is reached, but it presents the elements for active chemical exchanges. When I was a superintendent in Tombstone, two of my men, who were mining manganese in the higher strata of this limestone, nearly lost their lives by an effusion of CO_2 into a shallow, open pit where they were working. The gas accumulated during the night and surprised them in the morning. These facts may indicate the influence of carbon in that mining district.

At the New Almaden quicksilver-mine there is an enormous discharge of carbon dioxide, which bubbles and hisses through the water in the bottom, and twice, at least, has so filled the large chambers of the old mine as to drive the whole mining-force from its work.

The *Mining and Scientific Press*, San Francisco, of May 2, 1903, has the following interesting note upon the occurrence of carbon dioxide:

"Metal mines, as well as coal mines, produce carbonic acid gas, though more rarely the inflammable 'fire damp' In some instances the carbonic acid gas has been so abundant that the mining work has had to be abandoned. This was the case in a long drift from a deep shaft at the New Almaden, Cal., quicksilver-mine. Subsequently, an air-tight bulkhead was built in the drift, and pipes placed connecting an air-compressor at the surface with the bulkheaded drift. The intake of the compressor was attached to the pipe leading into the mine, the carbon

dioxide was drawn from the mine and by means of special machinery compressed into steel cylinders under a pressure of 1,200 lb. per sq. in., in which form it was sold for the carbonating liquids. The Abbott quicksilver-mine in Lake county, Cal., makes a large amount of 'fire gas' similar to the 'fire damp' of coal mines. The occurrence of fire damp in metal mines is unusual. In the case of the Abbott mine its presence is supposed to be due to the bituminous matter in the surrounding rocks."

Ore-Deposits Near Igneous Contacts.

Discussion of the Paper of Walter Harvey Weed, p. 715.

BY W. L. AUSTIN, NEW YORK CITY.

In Mr. Weed's interesting paper, frequent reference is made to the Cananea copper-deposits, which are said to have been so vigorously exploited that they produced 14,000,000 lb. of copper in 1901.

The ore-bodies which yielded this large quantity of metal are described as a product of contact-metamorphism, and in Mr. Weed's genetic classification of such deposits, they receive a place under the sub-heading, "Deposits impregnating and replacing beds of contact-zone."* They are considered by Mr. Weed to represent a special type under this head, and are further classified as: "1. Chalcopyrite deposits: (*a*) Pyrrhotite ores; (*b*) Magnetite ores, Cananea type."

In condensing much information into a comparatively small space, the presentation of a subject may be so abbreviated as to detract from its clearness. The situation at La Cananea, considering its importance from an economic as well as scientific standpoint, may be worthy of more detailed description. As Mr. Weed rightly remarks, "structural differences are so important, and have so marked a bearing, not alone on the theory of their genesis, but also on the working of the deposits and a determination of their value as mines, that they merit a full discussion."†

It is my present purpose: (1) to show that it is doubtful whether the copper of La Cananea is mined, except to a limited

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* Mr. Weed's paper, pamphl. ed., p. 7; and *ante*, p. 721.

† *Id.*, p. 10; and *ante*, p. 724.

extent, from contact-metamorphic deposits; (2) to emphasize the importance of the mineral-bearing porphyry in connection with the genesis of the Cananea deposits; and (3) to question the correctness of Mr. Weed's opinion that, in this locality, "the deposits should extend downward in depth to the granular rock."

Contact-metamorphic ore-deposits are very common in the West and Southwest. Among the better known of those in which copper is the principal economic mineral are those of the Seven Devils district, Idaho; Saline Valley, California; the Planet mine on Bill Williams Fork, Marble mountain, in the Santa Catalina mountains, and Clifton, Arizona; La Cananea, and the Santo Niño deposits on the Yaqui river, Sonora; Terassas Station, Chihuahua; and La Jibosa mine, Velardeña copper-mine, and Sacrificio mountain, Durango. There are many others which I have not personally visited, but concerning which I have received private communications, or have found described in current technical literature.

These may all be classed together as ore-deposits occurring at or near the contact of igneous rocks with limestone beds, and owing their existence to the presence of the eruptives.

This general type of deposit is recognizable at first sight; but it is not always with a simple contact that the observer has to deal. Associated with the actual contact ore-bodies are mineralized eruptives, fissure-veins and replacements in the limestone. Mr. Weed, recognizing the variations displayed by deposits of this description, has proposed a tentative classification, which might be further discussed to advantage.

By reason of the very nature of the genesis of these deposits, there must be much diversity among them. In fact, hardly any two of them are exactly alike. They all have a certain mutual resemblance, and differ radically from any other class; but, unless a broad significance is given to the term contact-metamorphism, it will scarcely cover them all, and, in any event, there will be almost as many "types" as deposits.

The selection of the Cananea deposits as typical of contact-metamorphism, and the ascription to this type the large production of copper quoted above, seems to me to be ill-advised; and the statement that in this instance the primary sulphide-

ore should continue of unchanged tenor in depth down to a hypothetical contact with granular rock, certainly calls for further elucidation.

There are numerous contacts between the limestone and the igneous rocks of the Cananea district;—in fact, all the limestone patches are almost surrounded by porphyritic rocks of one kind or another;—but neither at any one of the important mines, nor at any other points so far as I know, has a contact between the limestone and a granular igneous rock been observed.

The ore-deposits of *La Sierra de la Cananea*, as hitherto developed, are scattered through the mountains along a N.W.–S.E. belt for about 8 miles. Puertocito is at the extreme northern end of the belt; the Elisa mine at about the middle; Capote basin (with the Capote, Oversight, Veta Grande and Chivatera mines) are south of the Elisa; and at the southern end is the Cobre Grande mine. The Elenita deposits are really a part of Puertocito. At various points between these main ore-bodies are smaller ones.

At Puertocito and Elenita there are masses of garnetiferous minerals with associated copper carbonates and silicates, pyrite, chalcopyrite and bornite; at the Elisa there are irregular bodies of chalcopyrite along a fault-fissure in the metamorphosed limestone; at the Oversight and Capote mines there are much larger masses of feldspathic porphyry carrying chalcocite, which have yielded much the greater part of the copper produced in the district. The deposits of Elenita and Puertocito had no part in the large copper-production mentioned in Mr. Weed's paper; not until late in April, 1903, was any ore shipped from this part of the belt.

At the present time (April, 1903) the Oversight mine occupies the place of honor among the developed properties, having temporarily exceeded the production of the Capote, which was the first large *bonanza* found in the district. The first-class ore of the Oversight is a soft, white feldspathic porphyry, heavily mineralized with chalcocite. At the southern end of the mine, the surface-indications of underlying ore-bodies are so slight that one, not very familiar with the characteristics of deposits of this class, would hardly have ventured to predict the discoveries which have been made a few feet below. The por-

phyry shows at the top no mineralization; no gossan; no "copper stains." The solutions which effected the decomposition of the original pyrite, carried the iron with them and deposited it elsewhere,—a process which can be seen in operation to-day in other parts of the district. In such cases, silica and silicates are usually substituted for the minerals removed.

Underneath there is an ore-body of irregular shape, already developed for several hundred feet in depth, and in places several hundred feet wide. It is in reality a southerly continuation of the Capote ore-zone—a second great concentration of chalcocite in the porphyry. Its limits as here stated are merely those of the ore rich enough to be shipped; in fact, the chalcocite-bearing rock merges into cupriferous pyrite bodies of very much larger dimensions, but of lower grade. This much is known: but what is the extent of these ore-bodies, or how many more of them there may be, has not yet been ascertained. Only the first-class, and the higher grades of the second-class ore, are at present taken out; lower-grade material is left standing.

It is not my present intention to discuss the extent and value of the Cananea ore-bodies. That matter has been briefly touched upon, only in order to bring out the fact, that by far the greater part of the copper produced by the mines of La Cananea has come from masses of mineralized porphyry, and not from "chalcopyrite ore-bodies carrying accessory galena, . . . practically confined to the rocks resulting from the alteration of impure limestones."* A statement of this kind, coming from such an authority as Mr. Weed, might possibly cause others to feel warranted in making large expenditures upon deposits of the class indicated, basing their hopes on the supposition that the *bonanzas* of La Cananea were found in contact-metamorphic deposits, with a probability of their extending "downward in depth to the granular rock."

Porphyry is by far the predominating rock along the Cananea ore-belt. I use the term "porphyry" in its general sense, for there are several varieties. Possibly all varieties have had their origin in the same eruptive magma, the sub-species being due to magmatic differentiation, or to the incorporation of portions of other rocks with which the eruptives came into con-

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* *Id.*, p. 9; and *ante*, p. 723.

tact. In places is found typical quartz-porphyry; but where the ore-bodies occur, the quartz is not so much in evidence. There are in the district other varieties of igneous rocks, such as granite, diorite, diabase and andesite; but these are mostly at some distance from the ore-belt, and as far as I know are not mineralized to any noticeable degree. The porphyry, however, wherever it has been artificially exposed within the entire length of 8 miles here in question, is more or less pyritic, and in places the sulphides are massed so as to form ore-bodies. The mineral belt has been extensively prospected, and tunnels many hundreds of feet in length cross its trend in a number of places. In these tunnels, many of which are considerable distances away from the producing mines, this mineralized porphyry is exposed; and at such points its character can be studied to advantage. It extends from the mines on the extreme north to those on the extreme south, and is essentially the mineral-bearer of the district. The limestone occurs only in spots. Where the heavily mineralized porphyry has come into contact with this limestone, there are the usual contact-metamorphic phenomena; but these ore-bodies are of subordinate commercial importance; in fact, but for the mineralized porphyry the history of La Cananea would have been a totally different one.

The quartzites do not contain mineral deposits, except where cupriferous solutions from the decomposing porphyry have found cracks and fissures in which to deposit their burdens; and these are practically a negligible quantity.

Where the limestone has been metamorphosed by contact with the porphyries, it has become one of the most, if not the most, resistant of the rocks of the district. Proof of this statement is furnished by the garnetiferous bluffs which constitute such prominent landmarks at the Puertocito end of the belt. Not in this district only, but everywhere, such resistance to weathering is characteristic of rocks thus metamorphosed; for the process itself is largely one of silicification.

The ore-bodies which have made La Cananea famous are soft porphyritic masses, partly of mineralized porphyry, partly of dark-colored plastic clay less heavily charged with copper-ore. The one merges insensibly into the other, and much of the material is of a nondescript character, depending on the

degree of decomposition which the rock has undergone. It bears no resemblance to metamorphosed limestone, although fragments of that rock are found in it, as are also masses of quartzite.

It is common, where porphyritic flows have broken through limestone beds, to find included masses of the latter caught in, and surrounded by, the porphyry; and the Cananea deposits are no exception.

The ore is so soft that no amount of timbering can hold the workings open; the stopes have to be filled as soon as the ore is removed. The ground swells to such an extent that on the third level of the deep Capote workings the shaft can only be kept open by maintaining a passage-way around it. In the bottom of the mine the tops, sides and bottoms of the drifts are squeezed together, like those of a tunnel run into a bank of plastic clay. One peculiarity of the low-grade ore-bodies is, that although the rock may have lost its pristine character and may be as soft as stiff putty, the pyrite distributed through it is unoxidized and bright, even on its surface.

The ore from the Capote and Oversight mines comes to the concentrator and smelter mostly as whitish-gray clayey "fines." In the concentrator the Oversight ore in particular gives trouble, because it "thickens" the water, thereby preventing the mineral from separating out. On the concentrating-tables, garnets and similar minerals, characteristic of contact-metamorphism, are noticeably inconspicuous. At Puertocito the mineralized porphyry taken from one of the shafts "slacks" in the air to a powder.

That white feldspathic porphyry, similar to, if not identical with, that of *La Sierra de la Cananea*, may be itself a highly cupriferous mineral-bearer, is evidenced by the deposits at Ajo in southern Arizona, not far northwest of La Cananea. Here masses of mineralized porphyry form hills within a basin of other eruptive matter. The rock is pyritic throughout, and in places the ore is identical with that of the Capote basin. I noticed no sedimentary rocks at Ajo. The ore-bodies are porphyry, carrying pyrite, with chalcocite, and other cupriferous minerals.

At Clifton, also, notably on Metcalf hill, the mineralized porphyry, constituting the ore-bodies of the Arizona Copper Co.,

is of similar nature, if not the same, as that of Ajo and La Cananea. And the same may be said of the rock in which lies the large pyritic body of Iron mountain, in California.

For the reasons above given, and without wishing to disparage the statements of such an eminent and accomplished geologist as Mr. Weed, I question the propriety of describing the large copper-producing ore-bodies of La Cananea as a type of contact-metamorphic deposits. The porphyries have certainly taken a more important part in the genesis of these cupriferous deposits than that which he has assigned to them. At Puertocito, as well as in the Capote basin, it would seem to be more in accord with the facts to assume that the pyritic minerals brought up by the porphyry became, through magmatic differentiation, more concentrated in certain localities than in others, and that these heavily mineralized portions were very susceptible to attack from atmospheric waters. In the Capote basin, where the mineralization was the greatest, the porphyry yielded readily to decay, the result being the formation of ferric masses (gossan), which were left on or near the surface, and the concentration of the copper below in the form of chalcocite. The gossan found on the top of the ground is a fairly good flux, and is used as such; but it becomes more and more siliceous with depth, until it rests on the ore. It presents an irregular bottom-limit, penetrating the ore in places. Immediately under the gossan comes the chalcocite-bearing porphyry. At the junction of the two, native silver is sometimes found. The workings in this portion of the Capote mine were very hot; and the more it was attempted to ventilate them, the hotter they became. Quartz-sand also (used for building-purposes) was found in this zone.

The subject of the formation of chalcocite ore-bodies by the oxidation of pyritic minerals and subsequent precipitation of the copper sulphide on deeper-lying, unaltered ore, has been handled in such a masterly manner by Mr. H. V. Winchell, of Butte,* that it would be superfluous to go further into the matter here.

There are contact-metamorphic deposits at La Cananea; but they were of comparatively subordinate importance in con-

* *Engineering and Mining Journal,* vol. lxxv., p. 782.

nection with the output of copper in 1901, and they are still subordinate. The main ore-deposits are concentrations in the porphyry of chalcocite derived from cupriferous pyrite, which came up as an accessory component of the original rock.

A correct diagnosis of the genesis of an ore-deposit is of more than scientific interest; it is of great economic importance. A better appreciation of this truism by those in responsible charge of mining operations would result in the saving of vast sums of money which are uselessly expended at the present time.

In regard to the occurrence of arsenopyrite in, or close to, contact-metamorphic deposits, the case of Sacrificio mountain, in Durango, might be cited in addition to those mentioned by Mr. Weed. These deposits, which are typically contact-metamorphic in the sense given the term by Mr. Weed—"zones of altered sediments about igneous intrusions"*—are associated with veins of arsenopyrite.

The Geological Features of the Gold Production of North America.

Discussion of the Paper of Waldemar Lindgren (see p. 790).

Willet G. Miller, Toronto, Canada (communication to the Secretary): In his interesting paper Mr. Lindgren says: "As to ultimate results, it would seem as if we should be justified in concluding, with Prof. Suess, that the gold-supply of the world will gradually decrease if no further important improvements are made in the processes for the extraction of this metal; but regarding events so far distant no predictions may safely be made."

It seems to the writer that no very important improvements require to be made in order at least to keep up the present production for many years to come. In many parts of the world there are large deposits of auriferous material which can be worked if present conditions are slightly changed. In the territory occupied by the Archean protaxis of the Province of

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* Mr. Weed's paper, pamph. ed., p. 7; and *ante*, p. 721.

Ontario, for instance, there are gold deposits of large size which apparently could be worked at a profit if the cost of production were slightly decreased. Many of these deposits average approximately from $1 to $1.50 per ton, and consist of quartz-veins, shattered, impregnated masses of granite, and other rocks and placer-deposits.

In the Rainy River district in Western Ontario, gold occurs in a mass of rock which is thus described in the Government reports of the Province: "It consists of a mixture of altered granite, quartz and chlorite, with streaks of green schist. It has been traced 3 or 4 miles, and has a general direction of northeast and southwest. The boundaries are rather indefinite, but as near as can be ascertained it is 462 ft. wide at the widest known place. On the location we are dealing with it varies in width from 100 to 200 ft. One hundred feet is its width at the narrowest place, as far as known."* Judging from careful tests which have been made much of this rock-matter contains $1.50 value per ton in free-milling gold. It has not been found possible, however, to work it at a profit.

Gold has been found in the Vermilion River placers, north of Sudbury, in a territory covering many square miles.† The metal occurs free, usually in a state of very fine division, and inclosed in pebbles of quartz. Fire-assays show that the sand and gravel frequently carry a value of more than $2 per ton. Much of the material, while lower in value, averages from 12 to 15 cents per cubic yard. While the existence of these placers has been known for some years, success has not been achieved in treating them. It would seem, however, that a comparatively slight improvement in the present methods of treatment should bring about the profitable working of them.

A year or two ago similar placers were discovered on Savant lake, which is about 150 miles northwest of Port Arthur and 500 miles from the last-mentioned area. In panning these sands and gravel I obtained a very few colors. Fire-assays, however, show that much of the material, which consists of coarse sand, gravel and boulders, averages about $1 per ton in gold.‡ Some of the metal contained in the fragments of rock probably could not be extracted by free-milling processes.

* *Ont. Bureau of Mines Report*, vol. vii., p. 65. *Ib.*, pp. 130–131.

† *Ib.*, pp. 256–9, and vol. x., pp. 151–9. ‡ *Ib.*, vol. xii., pp. 89, 90.

Similar deposits, which have not been examined as to their gold-content, cover a large territory in this little-explored region, and it would appear that the metal is present in most of this gravel.* In the vicinity of Savant lake the thickness of the sand and gravel deposits is at some points over 100 ft. The deposits are of glacial origin, and the average of the gold-content of the gravel from the tops of the higher hills is similar to that found at lower levels.

The rocks over a great part of the Archean area of Canada are similar in character, and there is reason to believe that gold deposits carrying values like those mentioned occur widely extended over this vast, imperfectly-explored region. It may be many years, probably not till the production of the richer deposits of other parts of the world begin to decline, before these deposits are worked. Since the gold-values which they carry, however, are so close to those of deposits which even now are being profitably worked, it is within the range of probability that the Canadian protaxis will, in the years to come, be the scene of a great gold-industry. Low-grade deposits in other parts of the world also will then add their quota, and the day of a great decline in gold production, a time of "not only physical devastation, but moral and physical decay," thus seems far distant.

W. L. Austin, New York (communication to the Secretary): In Mr. Lindgren's instructive paper the statement is made in the reference to the pre-Cambrian gold-quartz veins of South Dakota and Wyoming, that "these two are the only localities in the Cordilleran region in which pre-Cambrian deposits have been recognized." Further along in the paper it is stated that "gold deposits of Archean age are not known in Colorado. As far as the age has been determined, the deposits are divided into a smaller Mesozoic and a much greater Tertiary and probably chiefly post-Miocene group."

Mr. Lindgren has apparently overlooked an extensive auriferous deposit described by Messrs. E. C. and P. H. van Diest in a paper read before the Colorado Scientific Society in 1894. As the article referred to is not readily accessible, and as the

* *Sum. Rep. Geol. Sur. Can.*, 1901, pp. 92–3.

said deposit is of considerable extent—the beds cropping out 3 miles in one direction, and 1 mile in another—a few extracts from the van Diest paper may be considered pertinent in discussing "The Geological Features of the Gold Production of North America." Furthermore, this matter has commercial importance, for these beds may become at an early day a not inconsiderable source of the precious metal.

The van Diests refer to this deposit as Cambrian; but it is thought that no serious attempt has been yet made to fix the age other than approximately. It is apparently lower than the Silurian, and in some respects resembles the pre-Cambrian deposits of the Black Hills.

Quoting from the van Diest paper: "The district examined is on the Rito Seco. This little stream unites with the Rio de la Culebra near San Luis—the county seat of Costilla county—a region nearly in the center of the lower neck of the Pliocene lakes, named by Endlich the Coronados lakes. Leaving San Luis, the Rito flows for about 6 miles in a northerly direction through scattered *débris*, when the lake beds forming the foot hills are reached. Here the road takes an easterly direction, winding its way for about 3 miles through a wide and shallow canyon which has been eroded from the lake beds. According to Hayden the lake beds at this point should lie against the Upper Carboniferous. No dark-red sandstones, such as were observed in coming over Veta Pass, could be seen anywhere, but we found instead, on the north side of the Rito for a distance of a quarter of a mile, some quartzite beds forming steep cliffs, while, further along, the stream flowed over light-colored limestones and finally over granite.

"Directly north of the creek a thin bed of conglomerate appears. It is composed of light-bluish and greenish quartz pebbles cemented by oxides of iron and manganese. Resting on this bed follow layers of quartzites whose total thickness is estimated at 160 ft. These quartzites are saccharoidal in appearance, of pure white color when freshly broken, but stained by a film of iron oxide where they have been exposed to the influence of the weather. The quartzites are succeeded by a thin bed of argillaceous shale, and the whole section is topped by layers of light-grey siliceous limestones for about 200 ft., where a quartzy parting separates them from others of somewhat

darker color. . . . Although no fossils have been found as yet in the described beds, it is clear from a stratigraphic point of view that the limestones are of Silurian and the quartzites of Cambrian age.* An igneous dike about 30 ft. in width runs through the limestone beds in a northerly and southerly direction. It is of a dark purplish-brown color, very compact and fine grained. In appearance it resembles more the older basalt occurring between the lake beds, and is distinctly different from the younger basaltic overflow which caps the beds south and west of the Rito Seco. The dike had had no disturbing influence whatever on the limestone beds, as is shown by the cuts run into the limestone on either side of the dike. Northerly and higher up on the mountain a light-colored porphyry was observed, but owing to lack of time there was no opportunity afforded to determine what the extent of this eruptive mass might be, and what connection, if any, it might have with the dike, nor could we determine if, in an easterly direction, other quartzites and limestones rest on the granite. . . .

"Close inspection of the rusty faces of the quartzite cliff has lately revealed that three distinct layers of auriferous iron pyrite occur between the quartzite beds, the lower one measuring about 12 ft. in thickness, the next about 14 ft., and the upper one 8 ft. At the time of our visit a drift had been run in the middle seam for a distance of 40 ft. The breast and sides of this drift stood in almost solid pyrite. This pyritic ore as broken down assays from $5 to $15 in gold per ton. So far no copper-, zinc-, or other sulphides have been observed with the deposit. The field, although but little employed, seems to be of promise, and it is to be hoped that development work will be uninterruptedly prosecuted."†

Since the above was written these quartzite beds have been exploited somewhat further; and it is now thought that the beds are more nearly an arkose than quartzite. This deposit is so little known that it is not surprising it should have escaped Mr. Lindgren's notice.

J. E. Spurr, Washington, D. C. (communication to the Secre-

* As Cambrian conglomerates bear witness to pre-Cambrian gold-veins, then these deposits must be pre-Cambrian in the same sense as those of the Black Hills.

† *Proc. Col. Sci. Soc.*, vol. v., pp. 76–80.

tary): Mr. Lindgren's paper constitutes a great addition to our knowledge of the general relations of North American gold-bearing veins. It is an important step in the work of marshaling facts into order, so that out of the confusing throng well-arranged groups, of definite significance, may result.

I wish, however, to take exception to Mr. Lindgren's conclusions concerning the gold-deposits of the Yukon district, Alaska. He says:

> "From data by Spurr, Brooks and Schrader, the placers were doubtless derived from veins in considerably altered sedimentary rocks, found in the vicinity, and called the Birch Creek, Forty Mile and Rampart series. These are of Paleozoic age, in part certainly Silurian. The age of the primary deposits is thus largely post-Silurian; and, as the placers are regarded as Pliocene, also pre-Pliocene. Most probably, these veins are Mesozoic, and of the same general period as the California deposits; but the possibility is not excluded that they may be older."*

Personally, I do not know of any evidence that the older and more important of the gold-bearing sedimentary series (the Birch Creek and the Forty Mile series) are Paleozoic, and not pre-Paleozoic, though they may be either. There is evidence, however, to show that the uppermost (and least important) gold-bearing series—the Rampart series—is Paleozoic, perhaps chiefly Silurian. Overlying these auriferous horizons, there have been found, on the Yukon, as well as in the neighboring regions, on the Tanana, the Kuskokwim, the Koyukuk, etc., heavy Devonian and Carboniferous limestones, which contain neither the gold-quartz veins nor the igneous (chiefly granitic) intrusions with which these veins appear to be genetically connected. This seems to indicate that the veins are pre-Carboniferous.

Another line of evidence, besides the lack of veins or dikes in the Devonian and Carboniferous limestones, may be cited. The oldest formation (the Birch Creek and the Forty Mile series) are crystalline schists, derived from the metamorphism of sediments. Overlying these is the Rampart series, consisting chiefly of extrusive basalts and derived tuffs. This shows no regional schistosity, and is schistose only in places, along certain zones. The Devonian and Carboniferous limestones are not schistose, and contain perfectly preserved fossils. There-

* Pamphlet edition, p. 24; *ante*, p. 813.

fore, the development of the schistosity was chiefly pre-Rampart. Perhaps the greater part of the auriferous veins, as well as the dikes in the gold-bearing schists, have been involved in the shearing or crushing, and have often been shredded to a great degree. Such veins seem, therefore, to be pre-Rampart. A later set of unsheared and uncrushed veins (probably less important), with accompanying dikes, intersects the schists; and it seems likely that it is the veins and dikes of this later period which appear in the Rampart series.

According to this view, the vein-formation, which is supposed by the writer to have been contemporaneous with the development of the schistosity and the dike-intrusion, must have gone on through a considerable period. The beginning of this period would be pre-Rampart (meaning, perhaps, early Silurian or Cambrian), and the close of the period would be late Silurian or early Devonian.

The above conclusions are the best that can be reached with the available data; and they apply only to the Yukon province. Certainly, many of the gold-bearing veins of the coast-belt in Alaska are of later age than those of the Yukon. Some of them are very likely Mesozoic; and, as Mr. Lindgren has noted, the writer himself has recorded probable Eocene auriferous veins in the Tordrillo mountains.

INDEX.

[NOTE.—In this Index the names of authors of papers are printed in small capitals, and the titles of papers in italics. References to papers expressly treating of the subject named are likewise in italics; and references to casual notices, giving but little information, are usually indicated by bracketed page-numbers.]

ERRATA.

1. In Vol. XXXI., on p. 1051 (Index), between the eighth and ninth lines from bottom of page, insert "BLAKE, W. P., *The Caliche of Southern Arizona: An Example of Deposition by Vadose Circulation*, 220 *et seq.*"

2. In the present volume, on p. 727, the quantity 140,000,000 lb. is obviously a clerical error. It should be 14,000,000 lb.; the actual production of copper reported officially by the Greene Consolidated Copper Co., for the year 1901, being 13,854,170 lb.